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A. D. M.	A. D. Mitchell, D.Sc., F.I.C. Assistant Editor of the *Journal of the Chemical Society.* Assistant Examiner in Chemistry, University of London and Institute of Chemistry.	**Polymerization.**
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E. J. F.	E. J. Forsdyke, M.A., F.S.A. Deputy Keeper of Greek and Roman Antiquities in the British Museum. Sometime Editor of the *Journal of Hellenic Studies*, Student of the British School of Archaeology at Athens and Secretary of the British School at Rome.	**Potteries and Porcelains** (*i* *part*).
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F. H. N.	F. H. Nixon. H.M. Treasury, London. Formerly Director of the Financial section of the Secretariat of the League of Nations. Member of British Official Financial Mission to Poland, 1924.	**Poland** (*in part*).

F. H. W.	Brigadier-General F. H. Williamson, C.B., C.B.E. Director of Postal Services, General Post Office, London. Director of Army Postal Services, 1915–9.	**Post and Postal Services** (*in part*).
F. J. H. M.	Hon. Frederick James Hamilton Merrill, Ph.D., F.G.S., M.A.Inst.M.E. Consulting Geologist and Mining Engineer. State Geologist of New York, 1899–1904. Author of *Reports* of New Jersey and New York Geological Surveys; etc.	**Quarrying.**
F. L. B.	Francis Lyall Birch, O.B.E., M.A. Lecturer in History in the University of Cambridge, and Fellow of King's College.	**Prime Minister;** **Privy Council.**
F. Ll. G.	Francis Llewellyn Griffith, M.A., Ph.D., F.S.A., F.B.A. Professor of and Reader in Egyptology, Oxford University. Editor of the Archaeological Survey and Archaeological Reports of the Egypt Exploration Fund.	**Psammetichus.**
F. M. S.	F. M. Stenton. Professor of History, University of Reading. Editor of the History (Mediaeval) section of the 14th Edition of the *Encyclopædia Britannica.*	**Poland** (*in part*).
F. O. B.	Frederick Orpen Bower, F.R.S. Formerly Emeritus Professor of Botany, University of Glasgow. Thrice President of the Botanical Section of the British Association and Ex-President of the Royal Society of Edinburgh. Author of *The Origin of a Land Flora; Plant Life on Land; Plants and Man;* etc.	**Plants** (*in part*); **Pteridophyta.**
F. R. C.	Frank Richardson Cana, F.R.G.S. Editorial Staff, *Encyclopædia Britannica,* 1903–11 and 1914–5. Staff of *The Times,* London, since 1916. Author of *South Africa from the Great Trek to the Union; The Great War in Europe; The Peace Settlement.*	**Portuguese East Africa** (*in part*).
F. Si.	F. Simon. Councellor of the Foreign Office, Berlin. Formerly Private Secretary to Herr Rathenau.	**Rathenau, Walther.**
F. T. W.	Frederick Theodore Weber. Etcher and Artist. Etchings in the Library of Congress, Washington; New York Public Library; Smithsonian Institution, Washington.	**Portrait Painting** (*in part*).
F. W. A.	Francis William Aston, Sc.D., F.R.S. Fellow of Trinity College, Cambridge. Nobel Prize for Chemistry, 1922. *See* the biographical article: Aston, Francis William.	**Positive Rays.**
G. A. P.	George A. Pfeiffer. Professor of Mathematics, Columbia University, New York.	**Polygons.**
G. A. R. C.	Geoffrey A. R. Callender, M.A., F.S.A. Secretary to the Society for Nautical Research and Professor at the Royal Naval College, Greenwich. Author of *The Naval Side of British History;* etc.	**Quiberon, Campaign and Battle of** (*in part*).
G. Buc.	Sir George Seaton Buchanan, C.B., M.D., B.Sc., F.R.C.P. Senior Medical Officer, Ministry of Health. Member of Court of Governors of London School of Hygiene, of Army Advisory Committee on Hygiene, and of Council Royal Society of Medicine.	**Public Health** (*in part*).
G. C. W.	George Charles Williamson, Litt.D., F.R.S.L. Chevalier of the Legion of Honour. Author of *Portrait Miniatures; Life of Richard Cosway, R.A.; George Engleheart;* etc. Editor of Bryan's *Dictionary of Painters and Engravers.*	**Prieur, Pierre.**
G. E. C.	George Earl Church. Explorer of the Amazon, 1868–79. Late Vice-President, Royal Geographical Society (London). *See* the biographical article: Church, George Earl.	**Plata, Rio de la** (*in part*).
G. E. E.	G. E. Ellis. Secretary, Committee on Automatic Train Control, American Railway Association, Chicago.	**Railways** (*in part*).
G. F. St.	George Frederick Stout, M.A., LL.D., F.B.A. Professor of Logic and Metaphysics in St. Andrews University.	**Psychology** (*in part*).
G. F. Z.	George Frederick Zimmer, A.M.Inst.C.E. Consulting Engineer and Joint-Editor of *Engineering and Industrial Management.*	**Pneumatic Conveying.**
G. G. A.	Major-General Sir George G. Aston, K.C.B. Lecturer on Naval History, University College, London. Formerly Professor of Fortification at the Royal Naval College, Greenwich. Author of *Sea, Land and Air Strategy; Memories of a Marine; The Navy of To-day.* Editor of *The Study of War.*	**Poland** (*in part*). **Portugal** (*in part*).
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G. H. Ga.	General George Henry Gater, C.M.G., D.S.O. Education Officer, London County Council. Formerly Director of Education, Lancashire County Council.	**Polytechnics.**
G. J. P	Gilbert Jocelyn Ponsonby, B.A. Assistant Secretary to the Railway Research Service, London School of Economics.	**Railways** (*in part*).
G. N.	Sir George Newman, K.C.B., M.D., F.R.C.P., D.P.H. Chief Medical Officer, Ministry of Health and Board of Education, London. Author of *An Outline of the Practice of Preventive Medicine; Recent Advances in Medical Education in England;* etc.	**Preventive Medicine** (*in part*).
G. S. B.	George Sidney Brett, M.A. Professor of Philosophy, University of Toronto since 1916. Professor of Ethics, Trinity College, Toronto, and Lecturer in the University of Toronto, 1908–16. Author of *Philosophy of Gassendi; History of Psychology;* etc.	**Psychology, History of.**

G. T. M.	Gilbert T. Morgan, O.B.E., D.Sc., F.I.C., F.R.S. Director, Chemical Research Laboratory, Department of Scientific and Industrial Research, London. Formerly Mason Professor of Chemistry, University of Birmingham, Professor in the Faculty of Applied Chemistry, Royal College of Science for Ireland and Professor of Applied Chemistry, Technical College, Finsbury. Author of *Organic Compounds of Arsenic and Antimony.* Contributor to Thorpe's *Dictionary of Applied Chemistry.* Editor of the Chemical section of the 14th Edition of the *Encyclopædia Britannica.*	**Pyrazoles;** **Pyrogallol;** **Pyrones;** **Pyrrole;** **Quinones.**
H. A. B.	H. A. Baylis, D.Sc. Assistant Department of Zoology, British Museum (Natural History).	**Platyhelminthes.**
H. Bp.	Rev. Herbert Louis Bishop. Missionary, Lourenço Marques, 1919–26.	**Portuguese East Africa** (*in part*).
H. C. C.	Henry Cope Colles, M.A., F.R.C.M., B.Mus. Musical Critic of *The Times*, London. Editor of third edition, Grove's *Dictionary of Music and Musicians.*	**Ravel, Maurice.**
H. C. L.	H. C. Long, B.Sc. Ministry of Agriculture and Fisheries, London. Editor of *Journal* of Ministry of Agriculture and Fisheries. Author of *Common Weeds of the Farm and Garden; Plants Poisonous to Livestock; Poisonous Plants on the Farm.*	**Poisonous Plants** (*in part*).
H. C. Ro.	H. C. Robbins. General Manager, Press Association.	**Press Association, The.**
H. Dev.	Henry Devine, O.B.E., M.D., F.R.C.P. Examiner in Psychology, Royal College of Physicians, London. Lecturer in Psychology, Maudsley Hospital, London. Medical Superintendent, Holloway Sanatorium, Virginia Water, England. Co-editor of *The Journal of Mental Science.*	**Psychosis** (*in part*).
H. E.	Haven Emerson, A.M., M.D. Professor of Public Health Administration, Columbia University, New York. Associate-Editor of *The Survey.*	**Public Health** (*in part*).
H. E. A.	Hugh E. Agnew, A.B., M.D. Chairman, Department of Marketing, New York University School of Commerce, Accounts and Finance. Author of *Co-operative Advertising by Competitors;* etc.	**Price-Cutting.**
H. E. Bar.	Harry Elmer Barnes, A.M., Ph.D. Professor of History and Sociology, Smith College, Northampton, Mass. Historian, New Jersey Prison Inquiry Commission. Author of *History of Penal Reformatory and Correctional Institutions of New Jersey; Progress of American Penology; The Repression of Crime;* etc.	**Prison** (*in part*).
H. E. Van Ge.	H. E. Van Gelder. Director of Service for Art and Science (incl. the Town Museums) of The Hague, Holland. Editor of *Oud. Holland.* Author of *Pottenbakkers; Kunst in Nedersland.*	**Potteries and Porcelains** (*part*).
H. Fi.	Herman Finer, D.Sc. Lecturer in Public Administration, London School of Economics. Author of *Foreign Governments at Work; The Case Against Proportional Representation;* etc.	**Proportional Representatio**
H. Fr.	Henri Frantz. Art Critic, *Gazette des Beaux Arts*, Paris.	**Puvis de Chavannes, Pier** **Cécile** (*in part*).
H. Fs.	Homer Folks, LL.D. Secretary of the State Charities Aid Association of New York. Chairman of the Executive Committee, Welfare Council of New York City. Author of *Care of the Destitute, Neglected and Delinquent Children;* etc.	**Poor Law** (*in part*).
H. G. B.	H. G. Beasley. Founder of the Cranmore Ethnographical Museum. Author of *Pacific Island Records.*	**Polynesia.**
H. J. R.	Herbert Jennings Rose, M.A. Professor of Greek, University of St. Andrews, Fife. Fellow and Lecturer of Exeter College, Oxford, 1907–11. Associate Professor of Classics, McGill University, 1911–5. Professor of Latin, University College of Wales, Aberystwyth, 1919–27. Author of *The Roman Questions of Plutarch; Primitive Culture in Greece; Primitive Culture in Italy; A Handbook of Greek Mythology;* etc.	**Prometheus** (*in part*).
H. L. Cr.	Harold L. Cross. Of the firm of Sackett, Chapman, Brown & Cross, Lawyers, New York.	**Press Laws** (*in part*).
H. M. Sp.	Henry M. Sperry. Publicity Representative of the Union Switch and Signal Company, General Railway Signal Company, New York.	**Railways** (*in part*).
H. M. T.	Horace M. Towner, LL.B. Governor, Porto Rico.	**Ponce;** **Porto Rico.**
H. N.	H. Nisbet, F.T.I. Textile Technologist and Consultant. Author of *Grammar of Textile Design.*	**Prunella.**
H. O.	Hermann Oelsner, M.A., Ph.D. Late Taylorian Professor of the Romance Languages in University of Oxford. Member of Council of the Philological Society. Author of *Frederic, Mistral; A History of Provençal Literature;* etc.	**Provençal Language and Literature** (*in part*).
H. R. M.	Henry R. Mussey, A.B., Ph.D. Professor of Economics, Wellesley College, Wellesley, Mass.	**Protection** (*in part*).
H. S. H.-S.	Henry Selby Hele-Shaw, D.Sc., LL.D., M.Inst.C.E., M.I.Mech.E., F.R.S. Emeritus Professor of Engineering, University of Liverpool. Ex-President, Institution of Mechanical Engineers, and Institution of Automobile Engineers, London.	**Power Transmission** (*in part*).
H. S. N.	Harry Stewart New, LL.D. Postmaster General, Washington, 1923–9. Former Editor and Publisher of *Indianapolis Journal.*	**Post and Postal Services** *part*).

H. T. A.	Rev. Herbert Thomas Andrews. Author of "The Commentary on Acts" in the *Westminster New Testament; Handbook on the Apocryphal Books in the* "Century" Bible.	**Polycarp** (*in part*).
H. T. N.	Harry T. Newcomb, LL.M. General Counsel of the Delaware and Hudson Company, New York. Author of *Railway Economics;* etc.	**Railways** (*in part*).
H. V. T.	H. V. Taylor, M.B.E., A.R.C.S., B.Sc., F.R.H.S. Horticulture Commissioner, Ministry of Agriculture and Fisheries, London.	**Potato: Cultivation, Production and Trade** (*in part*).
H. Wo.	Humbert Wolfe, C.B., C.B.E. Poet and Writer. Principal Assistant Secretary, Ministry of Labour. Substitute British Government Member, Governing Body International Labour Office. Author of *London Sonnets; Circular Saws; The Unknown Goddess; Cursory Rhymes;* etc.	**Poetry** (*in part*).
H. W. P.	H. W. Parker, B.A. Assistant in the Department of Zoology, Natural History Museum, South Kensington.	**Python;** **Rattlesnake.**
H. W. R.	Rev. Henry Wheeler Robinson, M.A., D.D. Principal of Regents Park College, London, since 1920. Formerly Professor of Church History and the Philosophy of Religion in Rawdon College, Leeds. Author of *Hebrew Psychology in Relation to Pauline Anthropology* (in Mansfield College Essays); etc.	**Psalms.**
H. W. S.	Henry Wickham Steed. Proprietor and Editor of *The Review of Reviews* since 1923. Editor of *The Times,* London, 1919 22. Lecturer on Central European History, King's College, London University. Engaged in propaganda in enemy countries, 1918.	**Propaganda.**
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J. A. S.	John Addington Symonds, LL.D. Author of *Renaissance in Italy; Studies of the Greek Poets;* etc. *See* the biographical article: Symonds, John Addington.	**Poggio** (*in part*); **Politian** (*in part*).
J. A. Th.	John Arthur Thomson, M.A , LL.D. Regius Professor of Natural History in the University of Aberdeen. Gifford Lecturer, St. Andrews, 1915. Terry Lecturer, Yale University, 1924. Author of *The Study of Animal Life; Outlines of Zoology; Heredity; Darwinism and Human Life; What Is Man?; Concerning Evolution.* Joint-Author (with Professor Patrick Geddes) of *Evolution; Sex, Biology.*	**Play in Animals;** **Protoplasm** (*in part*).
J. C. Os.	John Clyde Oswald. President of the New York Employing Printers Association, Inc. Formerly Editor of *The American Printer.* Author of *Benjamin Franklin, Printer.*	**Printing** (*in part*).
J. C. Su.	J. C. Sutherland, B.A. Inspector-General of the Protestant Schools of the Province of Quebec. Author of *The Province of Quebec: Geographical and Social Studies.*	**Quebec.**
J. E. Co.	J. E. Coates. Professor of Chemistry, University College, Swansea.	**Prussic Acid.**
J. E. S.	John Edward Sears, C.B.E., M.A., M.I.Mech.E., A.M.Inst.C.E., F.Inst.P. Deputy Warden of the Standards, Board of Trade, London, and Superintendent of the Metrology Department, National Physical Laboratory, Teddington, Middlesex.	**Precision Gauges and Comparators.**
J. F. C. F.	Colonel John Frederick Charles Fuller, C.B E., D.S.O. Military Assistant to the Chief of the Imperial General Staff. Chief General Staff Officer, Tank Corps, 1917–8. Formerly Chief Instructor, Camberley. Author of *Tanks in the Great War; Sir John Moore's System of Training;* etc.	**Pydna, Battle of.**
J. F.-K.	James Fitzmaurice-Kelly, Litt.D., F.R.Hist.S. Late Gilmour Professor of Spanish Language and Literature, University of Liverpool. Author of *A History of Spanish Literature.*	**Quevedo Y Villegas, Francisco Gômez de.**
J. G. Fr.	Sir James George Frazer, O.M., F.R.S. Author of *The Golden Bough.* *See* the biographical article: Frazer, Sir James George.	**Praeneste** (*in part*).
J. G. H.	James G. Harbord, B.S. Major-General, United States Army, retired. President of the Radio Corporation of America, New York.	**Radio Corporation of America.**
J. H.	John Hilton. Director of Statistics, Ministry of Labour, London.	**Pools, in Industry** (*in part*); **Profit-Sharing** (*in part*); **Rationalization of Industry.**
J. H. B.	Joseph H. Bonneville, A.M. Department of Banking and Finance, New York University School of Commerce, Accounts and Finance, New York. Author of *Elements of Business Finance.*	**Preferred Stock.**
J. H. Co.	Julius Henry Cohen, LL.B. Counsel for the Port of New York Authority; Special Attorney General, State of New York, in Housing Cases. Author of *Law and Order in Industry;* etc.	**Port Authority.**

J. H. McG.	James Howard McGregor, M.A., Ph.D. Professor of Zoology, Columbia University, New York. Author of various papers on reptilian and primate Palaeontology.	**Primates** (*in part*).
J. H. Mi.	John Henry Middleton, M.A., Litt.D., F.S.A., D.C.L. Slade Professor of Fine Art in the University of Cambridge, 1886–95. Director of the Fitzwilliam Museum, Cambridge, 1889–92. Art Director of the South Kensington Museum, 1892–6. Author of *The Engraved Gems of Classical Times; Illuminated Manuscripts in Classical and Mediaeval Times.*	**Raphael** (*in part*).
J. H. Mo.	J. H. Morgan, K.C. Professor of Constitutional Law, University of London. Brigadier-General, late Deputy Adjutant-General. Reader in Constitutional Law to the Inns of Court. Editor of the Law section of the 14th Edition of the *Encyclopædia Britannica.*	**Prerogative;** **Public Authorities Protectio Act.**
J. H. V. C.	Brigadier-General John Henry Verinder Crowe, C.B. Commandant of the Royal Military College of Canada, 1909–13. Formerly Chief Instructor in Military Topography and Military History and Tactics, Royal Military Academy, Woolwich. Author of *Epitome of the Russo-Turkish War, 1877–78;* etc.	**Plevna.**
J. Ke.	James Keeley. Assistant to the President of the Pullman Company, Chicago.	**Pullman Company, The.**
J. Mac.	Sir John Macdonell, C.B., LL.D. Late Master of Supreme Court, Quain Professor of Comparative Law, University College, London, and Editor of *State Trials; Civil Judicial Statistics;* etc. Author of *Survey of Political Economy; The Land Question;* etc.	**Protectorate.**
J. McG.	J. E. M. McGregor, A.C.G.I., A.M.I.E.E. Engineer-in-Chief's Office, General Post Office, London.	**Pneumatic Dispatch.**
J. McL. T.	J. McLean Thompson, M.A., D.Sc., F.L.S., F.R.S.E. Professor of Botany, University of Liverpool. Author of memoirs on the anatomy and affinity of ferns, and on the problems of floral structure, presented to the Royal Society of Edinburgh and in the publications of the Hartley Botanic Laboratories.	**Plants** (*in part*).
J. M. La.	J. M. Landis, A.B., LL.B., S.J.D. Professor of Legislation, Harvard Law School. Author of *The Business of the Supreme Court of the United States.*	**Police Power.**
J. Mof.	James Moffatt, M.A., D.D., D.Litt. Washburn Professor of Church History in Union Theological Seminary, New York. Formerly Professor of Church History, United Free Church College, Glasgow. Author of *The Presbyterian Churches;* etc.	**Presbyterianism** (*in part*).
J. O. McC.	John Oppie McCall, A.B., D.D.S. Professor of Periodontia, New York University College of Dentistry. Co-Author of *Textbook of Clinical Periodontia.*	**Pyorrhoea** (*in part*).
J. P. E.	Jean Paul Hippolyte Emmanuel Adhémar Esmein. Late Professor of Law in the University of Paris. Officer of the Legion of Honour and Membre de l'Institut. Author of *Cours élémentaire d'histoire du droit français.*	**Provost.**
J. P. P.	J. P. Postgate, M.A., Litt.D., F.B.A. Late Professor of Latin in the University of Liverpool and Fellow of Trinity College, Cambridge. Editor of the *Classical Quarterly.* Editor-in-Chief of the *Corpus Poetarum Latinorum;* etc.	**Propertius, Sextus.**
J. Rd.	John Read. Professor of Chemistry at the University of St. Andrews, Scotland.	**Pyridine.**
J. Ro.	John Ross, Ph.D., B.Sc., A.R.C.S., D.I.C. Research Chemist, Chemical Research Laboratory, Teddington, Middlesex.	**Quinoline.**
J. R. R.	John Robertson Riddell. Principal of the London School of Printing and Kindred Trades.	**Printing** (*in part*).
J. S. F.	Sir John Smith Flett, K.B.E., M.A., D.Sc., F.R.S. Director, Geological Survey of Great Britain and Museum of Practical Geology.	**Pneumatolysis;** **Porphyry;** **Pumice;** **Quartzite;** **Quartz-Porphyry.**
J. S. Fa.	John Shields Fairbairn, M.B., B.Ch., F.R.C.S., F.R.C.P. Obstetric Physician and Lecturer on Midwifery and Diseases of Women, St. Thomas's Hospital, and Consulting Physician, General Lying-In Hospital, London. Author of *A Textbook for Midwives; Gynaecology with Obstetrics;* etc.	**Puerperal Fever.**
J. W.	John Westlake, K.C., LL.D., D.C.L. Professor of International Law, Cambridge, 1888–1908. One of the members for the United Kingdom of International Court of Arbitration under The Hague Convention, 1900–6. Author of *A Treatise on Private International Law; Conflict of Laws.*	**Prescription** (*in part*).
K. F. D.	Major Knightley Fletcher Dunsterville, D.S.O., R.A. Inspector, Inspection Staff, War Office, London.	**Range-Finders** (*in part*).
K. G. J.	Kingsley Garland Jayne. Sometime Scholar of Wadham College, Oxford. Matthew Arnold Prizeman, 1903. Author of *Vasco da Gama and His Successors.*	**Portugal** (*in part*).
K. T. B.	Karl Bělař. Professor of Zoology, University of Berlin.	**Protozoa.**
L. B.	L. M. Brandin, Ph.D. Professor of French and of Romance Philology in the University of London.	**Provençal Language and Literature** (*in part*).
L. C. L.	Lionel Charles Liddell, M.V.O. Sometime British Consul at Copenhagen. Successively Secretary of the Restriction of Enemy Supplies Committee, and the Grand Committee on Trade in the War, 1914–8.	**Rationing of Neutrals (Blockade).**

INITIALS AND NAMES OF CONTRIBUTORS

L. C. M.	Sir Leo Chiozza Money, F.R.Stat.S., F.R.G.S., F.Z.S. Author and Journalist. Member of the War Trade Advisory Committee, 1915–8. Parliamentary Secretary to the Ministry of Shipping, 1916–8. Chairman of the Tonnage Priority Committee, 1917–8. Editor of the Economics, Engineering and Industries section of the 14th Edition of the *Encyclopædia Britannica.*	**Plaster-Work** (*in part*).
L. D. S.	Laurence Dudley Stamp, B.A., D.Sc., A.K.C., F.G.S., M.I.T.P. Sir Ernest Cassel Reader in Economic Geography in the University of London. Author of *An Introduction to Stratigraphy.*	**Pliocene;** **Quaternary.**
L. H. D. B.	L. H. Dudley Buxton, M.A. Reader in Physical Anthropology in the University of Oxford. Author of *Peoples of Asia.*	**Races of Mankind.**
L. J. S.	L. J. Spencer, M.A., Sc.D., F.G.S., F.C.S., F.R.S. Keeper of Department of Mineralogy, Natural History Museum, South Kensington. Formerly Scholar of Sidney Sussex College, Cambridge, and Harkness Scholar. Editor of the *Mineralogical Magazine.*	**Pollux or Pollucite;** **Quartz** (*in part*).
L. O. H.	Leland Ossian Howard, Ph.D., M.D., LL.D., Sc.D. Principal Entomologist, United States Department of Agriculture, Bureau of Entomology since 1878. Author of *Mosquitoes: How They Live; The Insect Book.*	**Plum Curculio.**
L. S. M.	Lewis S. Mudge, M.A., D.D., LL.D. Secretary of General Council of Presbyterian Church in the United States. Author of *The Manual of Law in the Presbyterian Church in the United States.*	**Presbyterianism** (*in part*).
L. S. Ma.	Lionel S. Marks, B.Sc., M.M.E. Professor of Mechanical Engineering, Harvard University. Author of *Mechanical Engineer's Handbook; The Airplane Engine;* etc.	**Power.**
L. Un.	Louis Untermeyer. Author. Travelling Lecturer at various universities in the United States. Editor of *Modern American Poetry; Modern British Poetry.* Author of *American Poetry since 1900.*	**Poetry** (*in part*).
M. A. J.	M. A. Jull, B.S.A., M.S., Ph.D. United States Department of Agriculture, Washington.	**Poultry and Poultry Farming** (*in part*).
M. B. L.	Mortimer Bliss Lane, A.B. Editor of *Survey of Current Business* (published by the United States Department of Commerce).	**Production, Census of** (*in part*).
M. C.	Max Cary, D.Litt. Reader in Ancient History in the University of London. Secretary to the Classical Association, 1911–4.	**Plataea;** **Punic Wars.**
M. Fi.	Morris Fishbein, B.Sc., M.D. Editor of *Journal of American Medical Association.*	**Quackery** (*in part*).
M. G. G.	Martin G. Gleaser, Ph.D. Professor of Economics, University of Wisconsin, Madison, Wis. Formerly Statistician, Railroad Commission of Wisconsin. Author of *Outlines of Public Utility Economics.*	**Public Utilities.**
M. J. Ro.	Milton J. Rosenhau. Professor of Preventive Medicine and Hygiene, Harvard Medical School. Formerly Director of the School of Public Health of Harvard University and Massachusetts Institute of Technology. Author of *Preventive Medicine and Hygiene;* etc.	**Preventive Medicine** (*in part*).
M. N. T.	Marcus Niebuhr Tod, M.A. Fellow and Tutor of Oriel College, Oxford. Reader in Greek Epigraphy. Joint-Author of *Catalogue of the Sparta Museum.*	**Pylos** (*in part*,.
M. S.	Morton Snyder, A.B. Head Master of the Rye Country Day School, and Member of the Progressive Education Association.	**Progressive Education Movement, The.**
M. W. A.	Magnus W. Alexander, M.S. President, National Industrial Conference Board, New York. Author of *Safety in the Foundry;* etc.	**Profit-Sharing** (*in part*).
N. B. J.	N. B. Jopson, B.A. Reader in Comparative Slavonic Philology, London University.	**Polish Language.**
N. D.	Mrs. Noëlle Davies, Ph.D.	**Prussia** (*in part*).
N. E. C.	Norman E. Crump. Statistical Correspondent to the *Financial Times,* London. Member of the Council of the Royal Statistical Society. Joint-Author of *Clare's A. B. C. of the Foreign Exchanges.*	**Pools, in Industry** (*in part*); **Pound Sterling.**
N. F. G.	Neil Forbes Grant, C.B.E., M.A. Foreign Editor of *The Morning Post,* London, 1918–25.	**Portugal** (*in part*).
N. W. McL.	Norman W. McLachlan, D.Sc.(Eng.), M.I.E.E., F.Inst.P. Chief Electrical Research Engineer, Telegraph Construction and Maintenance Company. Independent Research Engineer, Marconi Company, 1920–6. Inventor of various forms of radio and sound reproducing apparatus.	**Radio Receiver.**
O. C. H.	Olive Clio Hazlett, Ph.D. Assistant Professor of Mathematics, University of Illinois. Associate Editor of the *Transactions of the American Mathematical Society.* Member of the Council of the American Mathematical Society.	**Quaternions.**

O. H. T. R.	O. H. T. Rishbeth, M.A., F.R.G.S. Professor and Head of the Department of Geography, University College, Southampton.	**Queensland** (*in part*).
O. V.	Oswald Veblen, A.B., Ph.D. Professor of Mathematics, Princeton University, New Jersey.	**Projection, in Mathematic** **Projective Geometry.**
P. A. F.	Percy A. Francis, M.B.E. Poultry Commissioner, Ministry of Agriculture and Fisheries, London.	**Poultry and Poultry Farmin** (*in part*).
P. B.	Pierre Bernus. Foreign Editor of the *Journal des Débats*. Paris Correspondent of the *Journal de Genève*. Chevalier of the Legion d'Honneur.	**Poincaré, Raymond.**
P. G. K.	Paul G. Konody. Art Critic of *The Observer* and *The Daily Mail*, London. Author of *Velasquez, His Life and Work; The Brothers Van Eyck; Raphael; Fra Filippo Lippi;* etc.	**Post-Impressionism;** **Potter, Paul.**
P. L. G.	Paul L. Gerhardt, L.B. Vice-President and General Manager and Member of Board of Directors, Bush Terminal Company, New York.	**Port Operation** (*in part*).
P. R. S.	Paul R. Stillman, D.D.S., F.A.C.D. Clinical Professor of Periodontia, New York University. Post Graduate Lecturer, Harvard University. Co-Author of *Text Book of Clinical Periodontia.*	**Pyorrhoea** (*in part*).
P. V. B.	Percy V. Bradshaw. Principal, The Press Art School, London.	**Poster** (*in part*).
P. Z. C.	Major-General Sir Percy Z. Cox, G.C.M.G., G.C.I.E., K.C.S.I., F.R.G.S. Acting British Minister to Persia, 1918–20. High Commissioner in Mesopotamia, 1920–3. Secretary, Foreign Department, Government of India, 1914. Consul and Political Agent, Muscat, Arabia, 1899–1904.	**Qain;** **Qais.**
R. A. Lu.	R. A. Lundell, B. of M.E. Ingersoll-Rand Company, New York.	**Pneumatic Tools.**
R. B. F.	Raymond B. Fosdick, M.A., LL.D. Lawyer. Associate Editor, *American Journal Criminal Law and Criminology*, New York. Author of *European Police Systems; American Police Systems.*	**Police** (*in part*).
R. C. B.	Robert C. Brooks, Ph.D. Professor of Political Service, Swarthmore College, Pennsylvania. Author of *Corruption in American Politics and Life; Political Parties and Electoral Problems.*	**Progressive Party.**
R. Ch.	R. Chambers, M.A., Ph.D. Research Professor of Biology, New York University, and Chairman of the Department of Biology, Washington Square College.	**Protoplasm** (*in part*).
R. de W. C.	Robert de Wolf Coghill, A.B., M.S., Ph.D.	**Purines.**
R. Dy.	Roman Dyboski, Ph.D. Professor of English Literature in the University of Cracow (Poland). Corresponding Member of the Polish Academy. Member of the School of Slavonic Studies, University of London.	**Poland** (*in part*); **Polish Literature;** **Poznan or Posen** (*in part*).
R. F.	R. Firth, M.A., Ph.D. Member of the Polynesian Society. Author of *Primitive Economics of the New Zealand Maori.*	**Property, Primitive.**
R. F. F.	Robert Frederick Foster. Card Editor to the New York *Tribune*. Author of *Foster's Whist Manual; Foster's Bridge Tactics; Bridge Up to Date;* etc.	**Poker.**
R. F. K.	R. F. Kelley. Member, United States Polo Association. Polo Editor, *New York Times.*	**Polo** (*in part*).
R. H. Ra.	Robert Heron Rastall, Sc.D., F.G.S. University Lecturer in Economic Geology and Fellow of Christ's College, Cambridge. Member of Council of the Geological Society, 1915, and Mineralogical Society, 1918. Attached to War Office, 1915–9. Author of *Geology of the Metalliferous Deposits.* Editor of the Geology section of the 14th Edition of the *Encyclopædia Britannica.*	**Quartz** (*in part*).
R. J. T.	Richard John Tabor, B.Sc., F.L.S. Assistant Professor of Botany, Imperial College of Science and Technology, South Kensington.	**Plants** (*in part*).
R. L. Ho.	Robert Lockhart Hobson. Keeper of Department of Ceramics and Ethnography, British Museum. Author of *Worcester Porcelain; Chinese Pottery and Porcelain; The Later Ceramic Wares of China.*	**Potteries and Porcelains** (*part*).
R. L. Wi.	Raymond Louis Wilder, Ph.D. Assistant Professor of Mathematics, University of Michigan.	**Point Sets.**
R. M. Wh.	R. Mortimer Wheeler.	**Punch.**
R. N. B.	Robert Nisbet Bain. Assistant Librarian, British Museum, 1883–1909. Author of *Scandinavia: The Political History of Denmark, Norway and Sweden, 1513–1900; The First Romanovs, 1613 to 1725; Slavonic Europe: The Political History of Poland and Russia from 1469 to 1796;* etc.	**Poland** (*in part*); **Potemkin, Grigory Aleksandrovich.**
R. P.	René Poupardin, D-ès-L. Secretary of the Ecole des Chartes. Honorary Librarian of the Bibliothèque Nationale, Paris.	**Provence** (*in part*).

R. R.	Sir Richard Studdert Redmayne, K.C.B., M.Sc., F.G.S., M.Inst.C.E. Past President, Institute of Mining and Metallurgy. Hon. Member, Surveyors' Institute. H.M. Chief Inspector of Mines, 1908–20. Author of *The British Coal Industry.*	**Pulverized Fuel.**
R. R. M.	Robert Ranulph Marett, M.A., D.Sc., F.R.A.I. Rector of Exeter College, Oxford. University Reader in Social Anthropology. Author of *Anthropology; Psychology and Folklore.*	**Prayer.**
R. S. Cl.	R. S. Clay, B.A., D.Sc., F.Inst.P. Principal, Northern Polytechnic, Holloway, London. Author of *Practical Exercises in Light; Treatise on Practical Light.*	**Radiometer.**
R. S. Co.	Robert Seymour Conway, M.A., D.Litt. Hulme Professor of Latin, Victoria University of Manchester. Formerly Professor of Latin, University College, Cardiff, and Fellow of Gonville and Caius College, Cambridge.	**Praeneste** (*in part*).
R. Ta.	R. Taylor, M.A., B.Sc. Assistant, Chemical Research Laboratory, Teddington, Middlesex.	**Pressure Chemistry.**
R. W. P.	Raymond William Postgate. Editorial Staff of the 14th Edition of the *Encyclopædia Britannica.* Author of *The Bolshevik Theory; Revolution from 1789–1906; The Builders' History;* ed. *Pervigilium Veneris.*	**Radical.**
S. A.	Samuel Alexander, M.A., Litt.D., F.B.A. Hon. Fellow of Lincoln College, Oxford, 1918. Hon. Fellow of Balliol College, 1925. Hon. Professor (Professor, 1893–1924) of Philosophy, Manchester. Author of *Moral Order and Progress; Locke: Spinoza and Time;* etc.	**Qualities, Primary, Secondary and Tertiary.**
S. A. H.	S. A. Hurren. Lecturer on Technology of Pianoforte Construction at Northern Polytechnic Institute.	**Player-Piano.**
S. F. H.	Sir Sidney Frederic Harmer, K.B.E., M.A., D.Sc., F.R.S. Director of Natural History Departments, British Museum, 1919–27. Hon. Fellow, formerly Fellow, Tutor and Lecturer, King's College, Cambridge. Joint-Editor of *The Cambridge Natural History.*	**Polyzoa;** **Pterobranchia.**
S. Fr.	Sigmund Freud. Professor of Neurology, Vienna University. Director of the International *Journal of Psychoanalysis.*	**Psychoanalysis: Freudian School.**
Sh.	Thomas Shaw, Baron Shaw of Dunfermline, P.C., K.C., LL.B. Lord of Appeal. Lord Advocate for Scotland, 1905–9.	**Privy Council, Judicial Committee of the.**
S. K. L.	S. K. Lothrop, A.B., Ph.D. Anthropologist, Museum of the American Indian Heye Foundation, New York. Author of *Tulum: An Archaeological Study of Eastern Yucatan; Pottery of Costa Rica and Nicaragua; Pottery Types and Their Sequence in El Salvador.*	**Pokoman;** **Quiché.**
S. McC. L.	Samuel McCune Lindsay, Ph.D., LL.D. Professor of Social Legislation, Columbia University, New York. President, Academy of Political Science, New York. Author of *Social Aspects of Philadelphia Relief Work; Railway Labor in the United States; Child Labor Legislation.*	**Prohibition.**
S. Me.	Stanley Melville, M.D., M.R.C.S. Radiologist, St. George's Hospital, London. Radiologist, Charing Cross Hospital, West London Hospital and Hospital for Sick Children, Great Ormond St., London.	**Radiotherapy.**
S. Mo.	Stanley Morison. Editor of *The Fleuron,* London. Typographical adviser to the Lanston Monotype Corporation, London, University Press, Cambridge, and to Doubleday, Page and Co., New York. Author of *Four Centuries of Fine Printing;* etc.	**Printing Type** (*in part*).
S. Ru.	Sidney Russ. Professor of Physics, Medical School, Middlesex Hospital, since 1920. Physicist to the Middlesex Hospital since 1913. Fellow of University College, London. Co-Author of *Radium X-Rays and the Living Cell;* etc.	**Radiology.**
S. T. H. W.	Captain S. T. H. Wilton, R.N.(retired). Late Assistant Director of Naval Ordnance, Admiralty, London.	**Press Gang.**
S. W. C.	Sydney W. Cole, M.A. Lecturer in Medical Chemistry, Trinity College, Cambridge.	**Proteins.**
T. A.	Thomas Ashby, D.Litt., F.B.A., F.S.A., Hon.A.R.I.B.A. Formerly Director of the British School at Rome. Author of *Turner's Visions of Rome; The Roman Campagna in Classical Times; Roman Architecture.* Revised and completed for press a *Topographical Dictionary of Ancient Rome* (by the late Prof. J. B. Plattner). Author of numerous archaeological articles.	**Pompeii** (*in part*); **Praeneste** (*in part*), **Puteoli;** **Ravenna** (*in part*).
T. A. C.	Sir Theodore Andrea Cook. Late Editor-in-Chief of *The Field,* London. Author of *A History of the English Turf; The Art and Science of the Oar; The Fencer's Song;* etc. Editor of the Sports section of the 14th Edition of the *Encyclopædia Britannica.*	**Quoits.**
T. E. G.	Theodor E. Gregory, D.Sc. Sir Ernest Cassel Professor of Banking in the University of London.	**Quantity Theory of Money.**
T. F. H.	Talbot F. Hamlin, B.A., B.Arch. Instructor in the History of Architecture, Columbia University, New York. Chairman, City Plan Committee of the Merchants' Association, New York. Author of *The Enjoyment of Architecture; The American Spirit in Architecture.*	**Plateresque;** **Porch.**
T. G. Ba.	T. Graham Bailey, M.A., B.D., D.Litt. Reader in Hindustani in the University of London.	**Punjab** (*in part*).

T. H.	THOMAS HODGKIN, B.A. British Historian. Author of *Italy and Her Invaders; Theodoric the Goth; Life of Charles the Great. See* the biographical article: HODGKIN, THOMAS.	**Ravenna** (*in part*).
T. H. H.	COLONEL SIR THOMAS HUNGERFORD HOLDICH, K.C.M.G., K.C.I.E., HON.D.SC. Superintendent, Frontier Surveys, India, 1892–8. H. M. Commissioner for Perso-Beluch Boundary, 1896. President, Royal Geographical Society, 1916–8. Author of *The Indian Borderland; The Countries of the King's Award; India; Tibet;* etc.	**Quetta.**
T. J. E.	MAJOR T. J. EDWARDS. Secretary to the Honours and Distinctions Committee, War Office, London. Author of *The Perforated Map; The Non-Commissioned Officer's Guide to Promotion in the Infantry.*	**Quartermaster** (*in part*).
T. L. H.	SIR THOMAS LITTLE HEATH, K.C.B., K.C.V.O., SC.D., F.R.S. Hon. Fellow of Trinity College, Cambridge. Assistant Secretary to the Treasury, 1907–13. Author of *A History of Greek Mathematics;* etc.	**Porism;** **Ptolemy** (*in part*); **Pythagoras.**
T. N. McC.	THOMAS NESBITT MCCARTER, A.M. President, Public Service Corporation of New Jersey.	**Public Service Corporation New Jersey.**
T. W.	THOMAS WOODHOUSE. Head of Weaving and Textile Designing Department, Technical College, Dundee.	**Rain-Proof Fabrics.**
T. W.-D.	THEODORE WATTS-DUNTON. English Man of Letters. Author of *The Renascence of Wonder; The Coming of Love;* etc. *See* the biographical article: WATTS-DUNTON, WALTER THEODORE.	**Poetry** (*in part*).
U. P. H.	ULYSSES P. HEDRICK, D.SC. Director, New York State Agricultural Experiment Station, Geneva, N. Y.	**Plum** (*in part*); **Quince** (*in part*).
V. Bu.	VANNEVAR BUSH. Professor of Electric Power Transmission, Massachusetts Institute of Technology, Cambridge, Mass.	**Product Integraph.**
V. H. B.	VERNON HERBERT BLACKMAN, SC.D., F.R.S. Professor of Plant Physiology and Pathology, Imperial College of Science and Technology, London. Editor of the Botany section of the 14th Edition of the *Encyclopædia Britannica.*	**Plants** (*in part*); **Pollination;** **Potato.**
V. L. C.	VARNUM LANSING COLLINS, A.M. Secretary of Princeton University. Author of *The Continental Congress at Princeton; Guide to Princeton;* etc.	**Princeton University.**
W. A. L. E.	REV. WILLIAM ALEXANDER LESLIE ELMSLIE, M.A., B.D., HON.D.D. Professor of Hebrew and Old Testament Literature in Westminster College, Cambridge. Fellow of Christ's College, 1911–7.	**Prophet.**
W. A. R.	WILLIAM ALFRED REID, LL.M. Foreign Trade Adviser, Pan American Union. Lecturer on International Commerce at the School of Diplomacy, American University, Washington. Author of *Ports and Harbours of South America; History of the Pan American Union;* etc.	**Plata, Rio de la** (*in part*).
W. A. S. H.	WILLIAM ALBERT SAMUEL HEWINS, M.A. Secretary of the Tariff Commission, 1903–17. Formerly Director of the London School of Economics. Tooke Professor of Economic Science and Statistics at King's College, London, 1897–1903. Author of *Imperialism and Its Probable Effect on the Commercial Policy of the United Kingdom; Trade in the Balance; Empire Restored;* etc.	**Protection** (*in part*).
W. B. Ho.	W. B. HONEY. Assistant, Department of Ceramics, Victoria and Albert Museum, South Kensington.	**Potteries and Porcelains** (*part*).
W. Bro.	WILLIAM BROWN. Assistant Professor of Plant Physiology, Imperial College of Science and Technology, London.	**Plants** (*in part*).
W. C. B.	WILLIAM CABELL BRUCE, LL.B., LL.D. Member of the United States Senate, 1923–9. Author of *Benjamin Franklin, Self-Revealed; John Randolph of Roanoke.*	**Randolph, John.**
W. C. Br.	WARREN C. BROWNE. Editor and Publisher, *The National Lithographer,* New York.	**Printing Type** (*in part*).
W. C. B. T.	W. C. B. TUNSTALL, M.A. Civilian Lecturer, Royal Naval College, Greenwich.	**Quiberon, Campaign and Battle of** (*in part*).
W. C. Ha.	W. CLARKE HALL. Bencher of Grays Inn. Metropolitan Magistrate and Chairman of the Shoreditch Juvenile Court. Author of *The Law Relating to Children; The State and the Child; Children's Courts; The Law of Adoption;* etc.	**Probation** (*in part*).
W. C. S.	WALTER C. SANDERS. General Manager, Railway Division, The Timken Roller Bearing Company, Canton, Ohio. Licensed Professional Engineer (Mechanical), New York State. Author of *Railway Car Design and Construction.*	**Railways** (*in part*).
W. De B. H.	W. DE BRACY HERBERT. Barrister-at-Law. Recorder of Newcastle-under-Lyme.	**Quarter Sessions, Court o** (*in part*).
W. E. D.	W. E. DALBY, M.A., B.SC. M.INST.C.E., M.I.MECH.E., F.R.S. Dean of, and London University Professor of Engineering at, the City and Guilds Engineering College of the Imperial College of Science and Technology.	**Power Transmission** (*in part*).
W. F. C.	WILLIAM FEILDEN CRAIES, M.A. Late Barrister-at-Law, Inner Temple, and Lecturer on Criminal Law, King's College, London. Editor of Archbold's *Criminal Pleading* (23rd ed.).	**Quarter Sessions, Court o** (*in part*).

W. F. S.	WILLIAM FLEETWOOD SHEPPARD, SC.D., M.A., LL.M. Senior Examiner in the Board of Education. Formerly Fellow of Trinity College, Cambridge, and Senior Wrangler.	**Probability and Error.**
W. G. A.	WALTER GORDON ARMSTRONG. Assistant to the President, Youngstown Pressed Steel Co., Youngstown, Ohio.	**Pressed Metal.**
W. H. Sa.	WILLIAM HENRY SALTER, M.B.E., M.A., LL.B. Treasurer and Joint Hon. Secretary, Society for Psychical Research, London.	**Psychical Research.**
W. H. Wi.	SIR WILLIAM HENRY WILLCOX, K.C.I.E., M.D., B.SC., F.R.C.P. Physician and Lecturer on Chemical Pathology and on Forensic Medicine to St. Mary's Hospital, London. Medical Adviser to Home Office, 1919. Author of numerous original papers on medicine, chemical pathology, etc.	**Poison.**
W. K. G.	W. K. GREGORY, A.M., PH.D. Curator of the Departments of Comparative Anatomy and Ichthyology, American Museum of Natural History. Professor of Vertebrate Palaeontology, Columbia University. Author of *The Orders of Mammals;* etc.	**Primates** (*in part*).
W. La.	WILLIAM LATEY. Of the Middle Temple. Barrister-at-Law, of the Probate and Divorce Courts.	**Press Laws** (*in part*).
W. Li.	WALTER LIPPMANN, A.B. Editor of *The New York World.* Formerly Associate-Editor of *The New Republic.* Author of *The Political Scene; Liberty and the News; Public Opinion;* etc.	**Pulitzer, Joseph** (*in part*).
W. M. F. P.	SIR WILLIAM FLINDERS PETRIE, D.C.L., LITT.D., PH.D., F.B.A., F.R.S. Edwards Professor of Egyptology, University College, London. Founder of the British School of Archaeology in Egypt, 1894. Excavator of Giza, Naucratis, Am and Daphnae. *See* the biographical article: PETRIE, SIR W. M. F.	**Pyramid.**
W. O. B.	RT. REV. WINFRID OLDFIELD BURROWS, M.A., D.D. Bishop of Chichester. Formerly Bishop of Truro. Tutor of Christ Church, Oxford, 1884–91, and Principal of Leeds Clergy School, 1891–1900.	**Prayers for the Dead.**
W. P. H.	WALTER PAGE HEDDEN, A.M. Chief of the Bureau of Commerce, Port of New York Authority. Author of *City Produce Marketing.*	**Railways** (*in part*).
W. R. I.	VERY REV. WILLIAM RALPH INGE, D.D., C.V.O., F.B.A., HON.D.LITT., HON.LL.D. Dean of St. Paul's since 1911. Lady Margaret Professor of Divinity and Fellow of Jesus College, Cambridge, 1907–11. Gifford Lecturer, St. Andrews, 1917–8. Romanes and Hibbert Lecturer, 1920; etc. Author of *Lay Thoughts of a Dean; The Philosophy of Plotinus;* etc.	**Plotinus.**
W. R. Sm.	WILLIAM ROY SMITH, M.A., PH.D. Associate Professor of History, Bryn Mawr College, Pennsylvania.	**Polk, James Knox.**
W. Sco.	WALTER SCOTT. Member of the Royal Sanitary Institute, Institution of Heating and Ventilating Engineers, and Advisory Committee on Plumbing. Ex-President, Associated Master Plumbers. Technical Editor, *The Plumber and Journal of Heating.* Examiner in Plumber's work and Allied Sanitary Engineering, City and Guilds of London Institute. Late Chief Lecturer on Plumbing, The Polytechnic, London.	**Plumbing.**
W. Sh.	WILLIAM SHANKS. Of Messrs. Shanks & Co., Ltd., Barrhead, near Glasgow.	**Porcelain Enamelling.**
W. S. L.	W. S. LEWIS. Professor of Geography, University College, Exeter.	**Prague** (*in part*).
W. S. L.-B.	WALTER SYDNEY LAZARUS-BARLOW, M.D., F.R.C.P. Member of the Cancer Committee, Ministry of Health. Formerly Professor of Experimental Pathology, Middlesex Hospital Medical School, London University. Author of *A Manual of General Pathology; Elements of Pathological Anatomy and Histology for Students.* Editor of the Medicine section of the 14th Edition of the *Encyclopædia Britannica.*	**Pleurisy or Pleuritis;** **Purpura;** **Quackery** (*in part*).
W. Sta.	WILLIAM STANIAR. Mechanical Power Engineer and Division Head, Manufacturing Division, Dupont Engineering Company, Wilmington, Del. Author of *Mechanical Power Transmission.*	**Power Transmission** (*in part*).
W. S. Wa.	W. S. WALLACE, M.A. Librarian, University of Toronto.	**Quebec** (*in part*).
W. T. C.	WILLIAM THOMAS CALMAN, D.SC., F.R.S. Keeper of the Department of Zoology, British Museum. Author of "Crustacea" in Lankester's *Treatise on Zoology.*	**Pycnogonida.**
W. T. M.	RT. REV. WILLIAM T. MANNING. Bishop of New York since 1921. Formerly Professor of Dogmatic Theology in the University of the South.	**Protestant Episcopal Churc**
W. V. B.	W. VALENTINE BALL, O.B.E., M.A. Barrister-at-Law. Master of the Supreme Court, King's Bench Division. Author of *The Law of Libel as Affecting Newspapers and Journalists;* etc.	**Practice and Procedure** (*i part*).
W. Wi.	WILLIAM WILSON, PH.D., D.SC., F.R.S. Hildred Carlile Professor of Physics, University of London. Contributor of papers to the *Philosophical Magazine, Proceedings* of Royal Society and Physical Society, on Photoelectricity, Thermonics, Quantum Theory, Theory of Relativity; etc.	**Quantum Theory, The.**
W. W. P.	W. WYATT PAINE, J.P., F.S.A. Author and Editor of numerous legal textbooks.	**Police** (*in part*).
W. Y.	REV. WILLIAM YOUNG. Minister, Higher Broughton Presbyterian Church, Manchester, 1877–1901. Late Association Secretary for the Religious Tract Society in the North of England.	**Presbyterianism** (*in part*).

THE
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PLANTS TO RAYMUND OF TRIPOLI

PLANTS. In the most generally used sense a plant is a member of the vegetable class of living things, plants and animals being the two classes into which living things (organisms) are roughly divided. With the higher forms the difference is very definite and leaps to the eye. In the case of lower forms of life the distinction is often very difficult and indeed an artificial one, since plants and animals have had common ancestors in evolution. The early use of the word was for a twig, shoot, cutting or sapling which is the meaning of the Latin *planta.*

Other meanings of the word are derived from the verb "to plant" *i.e.,* to fix in position or place. It is thus used of the fixtures, machinery or apparatus necessary for carrying on an industry or business; in colloquial or slang use it is applied to a swindle, a carefully arranged plot or trap laid to deceive. (*Cf.* also PLANTATION.) In the following sections the botanical sense of the term is followed. An outline of the classification of plants is given under BOTANY and the chief groups, Algae, Fungi, Gymnosperms, etc., are dealt with in separate articles.

CLASSIFICATION OF PLANTS

In the article BOTANY reference has been made to the earlier systems of classification and the evolution of the idea of a natural system in which families are grouped according to their affinities. Details of classification *within* the large groups are given in the special articles on these groups. An outline of the generally accepted system of classification of the groups themselves is given below.

Plants are usually divided into CRYPTOGAMS, in which there are no flowers producing seeds, the sexual reproductive organs being inconspicuous, and PHANEROGAMS, in which the plants bear flowers or flower-like structures from which seeds arise. The term SPERMOPHYTA is sometimes used for Phanerogams. To the more complex Cryptogams which show vascular strands (*see* PLANTS: *Anatomy*) the term Vascular Cryptogams is often applied.

Cryptogams.—The lower groups of Cryptogams are classified as THALLOPHYTA, *i.e.,* plants possessing a thallus or plant body which shows no differentiation into stem and leaves. The large groups of the Thallophyta are the PROTOPHYTA, the most primitive group of plants; ALGAE, a group mostly of aquatic plants, showing various coloured pigments (green, red, brown, etc.); BACILLARIALES or DIATOMS, a group of minute, brown plants someti classed with the Algae; and the FUNGI and BACTERIA, which colourless parasitic or saprophytic plants probably derived reduction from alga-like ancestors. To all these groups spe articles are devoted, and also to the lichens, which are a pecu group of composite plants, consisting of an alga and a fun living in association.

The BRYOPHYTA (*q.v.*), which include the liverworts and Musci or true mosses, are distinguished from the Thallophyta the fact that the plant body often shows a distinction into st and leaves, and the female reproductive organs are structu known as archegonia.

The group PTERIDOPHYTA, or fern-like plants, includes all cryptogams higher than the Bryophyta. The plants often sho marked differentiation into leaves, some of these being of v great size and much divided. Furthermore they show well mar vascular strands (*see* p. 6) and their female reproductive org are archegonia. This large group includes the Filicineae (ferns), the Equisetineae (horsetails, etc.); the Lycopodin (club-mosses, etc.) and the Pteridospermae (a fossil group) wh are described under PALAEOBOTANY.

Phanerogams.—To this group, which is sometimes tern SPERMOPHYTA (or *Spermatophyta*), all the higher plants belo It includes the GYMNOSPERMS, in which the seed is not enclo in an ovary and the male and female reproductive organs are found contained in a single flower, and the ANGIOSPERMS, which the seed is not naked but enclosed in an ovary and male and female reproductive organs (stamens and carpels) usually associated in a single flower.

Classification of Angiosperms.—This very large group of pla falls into two classes, MONOCOTYLEDONS and DICOTYLEDONS. first being characterised by an embryo with one cotyledon (se leaf), a stem which usually shows no secondary thickening, a flowers with parts in threes. The second shows an embryo w two cotyledons, a stem which exhibits secondary thickening, a flowers with parts in fours or fives. The classification of ang sperms which is now usually followed, is that of A. Engler, monocotyledons and dicotyledons being divided into a number classes termed orders (or cohorts or series), the name of e order usually terminating in *-ales.* Each order includes a num of *families* (formerly termed "natural orders") many of which dealt with in special articles; the name of the family usua terminates in *-aceae.*

An outline of Engler's classification is given below, the orders (series) being printed in block type and the families in italics. For the 11 orders of Monocotyledons a synopsis of the chief characteristics is given. A selection of the more important families is made in the case of the orders which include a large number of families.

MONOCOTYLEDONS

Order 1. **Pandanales**—(Marsh herbs or shrubs or trees with large narrow leaves and compound heads or spikes of flowers. Seeds rich in endosperm.) *Typhaceae, Pandanaceae, Sparganiaceae.*

Order 2. **Helobieae**—(Water or marsh plants with cyclic or hemicyclic flowers, often enclosed in a spathe. Embryo large with little or no endosperm.) *Potamogetonaceae, Najadaceae, Alismaceae, Butomaceae.*

Order 3 **Triuridales**—(Saprophytes with scaly leaves and small long-stalked flowers.) *Triuridaceae.*

Order 4. **Glumiflorae**—(Usually annual or perennial herbs with naked flowers covered by bracts. Ovary unilocular with one ovule.) *Graminaceae, Cyperaceae.*

Order 5. **Principes**—(Plants often trees, leaves of large size often fan-like or feather-like, male and female flowers usually in spikes enclosed in a spathe, ovary superior and fruit a berry or drupe with rich endosperm.) *Palmaceae.*

Order 6. **Synanthae**—(Often palm-like or climbers or large herbs with male and female flowers arranged alternately over the surface of a spike.) *Cyclanthaceae.*

Order 7. **Spathiflorae**—(Herbaceous or woody plants, sometimes climbing, flowers on a simple spike [spadix] more or less enclosed in a bract.) *Araceae, Lemnaceae.*

Order 8. **Farinosae**—(Herbaceous or sometimes grass-like in habit, flowers cyclic, hermaphrodite or unisexual, androecium often reduced, ovary usually orthotropous, endosperm mealy.) *Bromeliaceae, Commelinaceae, Pontederiaceae.*

Order 9. **Liliiflorae**—(Usually herbs, often with bulb, corm or rhizome, perianth petaloid or glume-like; ovary trilocular superior or inferior; fruit a capsule or berry; ovule anatropous; endosperm fleshy or oily.) *Juncaceae, Liliaceae, Amaryllidaceae, Dioscoreaceae, Iridaceae.*

Order 10. **Scitamineae**—(Tropical, large, perennial herbs often with sheathing leaves; flowers hermaphrodite and irregular, androecium often reduced; ovary inferior usually trilocular; fruit, a berry or capsule with numerous seeds with much perisperm, little or no endosperm.) *Musaceae, Zingiberaceae, Cannaceae.*

Order 11. **Microspermae**—(Flowers of a pentacyclic trimerous type but often with great reduction in the stamens; ovary inferior; fruit, a capsule with numerous minute seeds containing a very small undifferentiated embryo.) *Orchidaceae, Burmanniaceae.*

DICOTYLEDONS

ARCHICHLAMYDEAE.—(Flowers often without a perianth, usually polypetalous; pollination entomophilous in the lower orders, anemophilous in the higher orders.)

Order 1. **Verticillatae**—*Casuarinaceae.*
Order 2. **Piperales**—*Piperaceae, Chloranthaceae.*
Order 3. **Salicales**—*Salicaceae.*
Order 4. **Garryales**—*Garryaceae.*
Order 5. **Myricales**—*Myricaceae.*
Order 6. **Balanopsidales**—*Balanopsidaceae.*
Order 7. **Leitneriales**—*Leitneriaceae.*
Order 8. **Juglandales**—*Juglandaceae.*
Order 9. **Batidales**—*Batidaceae.*
Order 10. **Julianiales**—*Julianiaceae.*
Order 11. **Fagales**—*Betulaceae, Fagaceae.*
Order 12. **Urticales**—*Ulmaceae, Moraceae, Urticaceae.*
Order 13. **Proteales**—*Proteaceae.*
Order 14. **Santalales**—*Santalaceae, Loranthaceae, Balanophoraceae.*
Order 15. **Aristolochiales**—*Aristolochiaceae, Rafflesiaceae, Hydnoraceae.*
Order 16. **Polygonales**—*Polygonaceae.*
Order 17. **Centrospermae**—*Chenopodiaceae, Amarantaceae Phytolaccaceae, Caryophyllaceae.*
Order 18. **Ranales**—*Nymphaeaceae, Ranunculaceae, Berberidaceae, Magnoliaceae, Lauraceae.*
Order 19. **Rhoeadales**—*Papaveraceae, Cruciferae, Resedaceae*
Order 20. **Sarraceniales**—*Sarraceniaceae, Nepenthaceae, Droseraceae.*
Order 21. **Rosales**—*Podostemaceae, Crassulaceae, Saxifragaceae, Hamamelidaceae, Platanaceae, Rosaceae, Leguminosae.*
Order 22. **Pandales**—*Pandaceae.*
Order 23. **Geraniales**—*Geraniaceae, Oxalidaceae, Tropaeolaceae, Linaceae, Rutaceae, Meliaceae, Polygalaceae, Euphorbiaceae Callitrichaceae.*
Order 24. **Sapindales**—*Buxaceae, Empetraceae, Aceraceae Sapindaceae, Balsaminaceae.*
Order 25. **Rhamnales**—*Rhamnaceae, Vitaceae.*
Order 26. **Malvales**—*Tiliaceae, Malvaceae, Sterculiaceae.*
Order 27. **Parietales**—*Dilleniaceae, Ochnaceae, Elatinaceae Cistaceae, Bixaceae, Violaceae, Passifloraceae, Begoniaceae.*
Order 28. **Opuntiales**—*Cactaceae.*
Order 29. **Myrtiflorae**—*Thymelaceae, Elaegnaceae, Lythraceae, Rhizophoraceae, Myrtaceae, Onagraceae, Hippuridaceae.*
Order 30. **Umbelliflorae**—*Araliaceae, Umbelliferae, Cornaceae.*

SYMPETALAE—(Flowers usually sympetalous, *i.e.*, with the part of the corolla more or less united, often resulting in a tubula flower.)

Order 1. **Ericales**—*Pyrolaceae, Ericaceae, Epacridaceae.*
Order 2. **Primulales**—*Myrsinaceae, Primulaceae.*
Order 3. **Plumbaginales**—*Plumbaginaceae.*
Order 4. **Ebanales**—*Sapotaceae, Ebenaceae.*
Order 5. **Contortae**—*Oleaceae, Gentianaceae, Apocynaceae Asclepiadaceae.*
Order 6. **Tubiflorae**—*Convolvulaceae, Polemoniaceae, Boraginaceae, Verbenaceae, Labiatae, Solanaceae, Scrophulariaceae Bignoniaceae, Orobanchaceae, Acanthaceae.*
Order 7. **Plantaginales**—*Plantaginaceae.*
Order 8. **Rubiales**—*Rubiaceae, Caprifoliaceae, Adoxaceae Valerianaceae, Dipsaceae.*
Order 9. **Cucurbitales**—*Cucurbitaceae.*
Order 10. **Campanulatae**—*Campanulaceae, Compositae.*

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(V. H. B.)

MORPHOLOGY OF PLANTS

The morphology of plants consists in their comparative study from the point of view of *Form.* It treats not only of the external contour of the plant-body, *External Morphology;* but also of the internal contours of the constituent tissues, as revealed by anatomical study, the *Morphology of Tissues.* For the full understanding of form it does not suffice to examine the adult state only. It was found early that difficult questions of comparison could be illuminated by observation of development of the individual, that is, of its *Ontogeny.* This led to views based upon comparison as to the historical origin and descent of the parts compared, or even of the plant as a whole. A further step to the study of the parts as organs, carrying out certain distinct functions, gives the aspect now designated as *Organography.* These methods of enquiry are used collectively as a basis for evolutionary or systematic conclusions. But such conclusions are apt in critical cases to take the form of expressions of opinion which may differ widely. In arriving at a decision the most positive source of knowledge is the evidence of geological succession in time, and comparison of the forms constituting that succession. This is yielded by the study of fossil plants, called *Palaeophytology* or *Palaeobotany* (*q.v.*). But its record is so incomplete as to leave many problems unsolved. The morphology of plants thus conceived bears within it the possibility of reconstructing the evolutionary history of the vegetable kingdom, which is the goal to which all such study converges. This is called *Phylogeny*.

Pre-evolutionary and Evolutionary Morphology.—The aspect of morphology thus sketched is modern, dating in its present form from the period of the *Origin of Species*. But with varying success pioneer efforts had been made to found a science of plant-form before 1859, when Darwin's book was published. At first these related to the parts that constitute the plant-body as seen in the higher flowering plants. The foundation of organography was traced to Aristotle by Vines. More recently classification of members of the plant-body by Jung (1657), and observations on their ontogeny by Wolff (1759) resulted in a view summarized by the latter in these remarkable words: "In the entire plant whose parts we wonder at as being, at the first glance, so extraordinarily diverse, I finally perceive and recognize nothing beyond leaves and stem, for the root may be regarded as a stem. Consequently all parts of the plant, except the stem, are modified leaves." With such a conclusion already before him it was an easy step for Goethe (1790) to enunciate his theory of Metamorphosis of Plants: in particular he visualized an ideal leaf of the nature of a foliage leaf, of which the bracts and floral parts were held to be metamorphosed types.

The theory of evolution, long entertained before but galvanized into active existence by the genius of Darwin, revolutionized morphology (*Origin of Species*, 1859). For those whose vision was clear it converted it at a single stroke from a deductive handling of abstract ideas based chiefly on the higher plants, to an inductive argument rising, as Bacon said, successively from particulars to axioms of the lowest generality, then to intermediate axioms, and so to the highest.

This newer evolutionary or phyletic morphology, better designated as organography, starts with simple unicellular and aquatic organisms, such as the Flagellates. Each is a minute naked protoplast of inconstant form. A first step towards definite plant-organization is *encystment* within a firm cell-wall: this state appears as an incident in the life of many Flagellates, the encysted cell taking an approximately spherical form. Growth of such a green cell gives better opportunity for nutrition, and for storage of the material acquired: and an enlarging spherical form may be retained by organisms that float in the uniform medium of water. But the relation of an enlarging body to external conditions not uniform is liable to result in *polarity*, with the fundamental distinction of *apex* and *base*. The latter commonly attaches itself to any solid substratum, even without division of the single cell. But usually cell-division follows upon increasing size. If polarity be strongly marked, and growth continued, a filamentous plant-body may result, consisting of a chain of cells attached at its base. This may be further elaborated by cleavage of cells and by branching, while still attached at its base. In this we see initiated another leading characteristic of plant-organization, viz., *fixity of position*.

The sacrifice of mobility consequent on a fixed position is seen in all but the simplest plants: it accords well with the requirements of a self-nourishing green organism, but it imposes limits upon certain of the essential functions of competitive life. The nourishment of the plant must be brought to it by external agencies, such as diffusion, and absorbed from the medium, molecule by molecule. A raptorial habit, as in animals, is then unnecessary, and is even precluded by the fixed habit. On the other hand, the propagative cells must either themselves be motile or must be easily spread by external forces: otherwise any extension of field would be impossible. Throughout descent these two facts have dominated the morphological evolution of plants.

Since all nutrition is primarily a function of surface, the larger the size of the organism and the more complicated its form, other things being equal, the better the nourishment of the individual, and the greater will be its propagative capacity. In simple organisms increase in size may be general throughout the plant-body. But in all larger plants *growth is localized.* Sometimes it is *intercalary* at some point between apex and base; but usually it is distal or apical. Where tissue-formation is thus localized the cells involved in it retain their youth as embryonic cells: this is especially marked at the distal tip, which has thus the character of a *growing point,* or *punctum vegetationis.* Here not only is provision made for continued growth of a central axis, but also for the initiation of successive branchings, which often mature as lateral appendages upon it. The result in the higher plants is the leafy shoot. These elaborations of the vegetative system may be seen illustrated either in the successive stages of an individual life, or by comparison of distinct organisms, such as a seaweed, a liverwort, a fern or a flowering plant. With varying detail these all share that distinctive feature of the more elaborated plant-body, its *continued embryology.* In all the higher animals the embryonic phase is a transient step towards full development, resulting in limbs definite in number and position: but plants have the power of forming an indefinite number of parts, in a succession theoretically without term or limit. Every bud of a forest tree or of a herb contains its own growing point deeply embedded among the successive leaves it has produced, and holds the potentiality of unlimited further development. *This continued embryology is the leading feature in the organization of the enlargin plant-body.*

Categories of Parts.—The vegetative system of the mor highly organized plants consists of parts which have been classe as *stem, leaf, root, emergence* and *hair.* So long as the mor highly organized plants alone are studied these categories appea fairly distinct. But when such comparison is applied to includ forms lower in the scale, the less complete differentiation of thei parts raises many questions touching the evolutionary origin o the several categories themselves. Here the fossil evidence take its place: for conclusions based upon structure, position, individua development or comparison are liable to be checked by the dis covery of some ancient form that may raise a doubt, or presen even a firm negative. Thus the conception of a leaf as a latera appendage upon a stem that is fixed at its base by roots, involve three categories of parts well marked in the higher vascular plant How does this accord with the existence of the Devonian foss *Hornea,* which is a vascular plant without leaves or roots It is clear that those categories are not absolute, but are result of evolutionary history still incomplete in *Hornea.*

Many difficult questions as to the category of parts are apt t arise when we attempt their classification in plants at large. Mer comparison of external form or even of internal structure will n suffice: decisions must be based upon the origin and the plac which the parts take relatively to other parts at the time whe they first appear. Following this method, those parts of t individual, or of different individuals, species or genera, ha been distinguished as *homologous* which bear the same relation t the whole plant-body, whatever their form or function or extern conditions may be. On the other hand, parts may resemble o another in form and in function, though they may differ in the relation to the whole plant-body. Such parts have been d scribed as *analogous* one with another. For instance, the fl green organs of the butcher's broom are by origin axillary bud not leaves. Though their main function is like that of leave nutritional, they are only analogous to leaves.

Homology presents a more difficult problem, for in plants the may be various degrees of that closer correspondence of par connoted by the term. The strictest conception of homology that designated *homogeny,* which may be defined as includi those structures which are genetically related in so far as the have a single representative in a common ancestor (Lankester This implies repetition of an individual part bearing a defini relation to the whole organism. In plants with their continue embryology such correspondence is rarely possible, owing to t indefinite number of appendages produced. And yet the leaves a shoot are comparable in other respects; but their homology can only be recognized in a less stringent sense than homogeny. Further, it may be held as doubtful whether all such parts as those designated "leaves" represent any essential plan of construction applicable to plants generally. The question arises whether leaf-like organs may not have originated independently in distinct phyletic lines: for instance, among the higher Algae, the Bryophytes, and the vascular plants. These diverse leaf-like organs may rather be regarded as being based upon such uniformity of results as has been achieved polyphyletically in descent, that is, by various types of organisms independently. In that case their likeness would be described as *homoplastic* (Lankester).

Limiting Factors.—Given a sufficient nutritive supply, continued growth of the plant-body may bring the organism up against certain limiting factors, of which the most obvious are concerned with mechanical stability, and the preservation of a due balance between surface and bulk, whether of the external contours, or of the internal tissue-surfaces. The *size-factor* may thus dominate not only the possible dimensions, but also the form of the plant-body and of its constituent tissues. The underlying principle is that of "similar structures," long ago recognized by Galileo, and familiar to architects and engineers. Applying it mechanically the strength of a structure varies as the square of the linear dimensions, and the mass or weight as the cube. Any plant endowed with continued growth, and with branching, is constantly approaching a size-limit defined by mass versus strength. Somewhat more than 300ft. is the extreme practicable height for a tree with the usual proportions and type of construction of the trunk, branches and twigs. A higher trunk would bend or break under the stress of wind.

The size-factor is also an effective influence on form; this is seen in respect of the proportion of surface to bulk. If the same form is maintained in an enlarging body, its surface increases as the square, while the bulk increases as the cube of the linear dimensions. Since nutrition and transit of materials are dependent upon surface action, the maintenance of a due proportion of surface to bulk in an enlarging organism may become critical. Its effect may be traced externally in the subdivision of submerged leaves, or indeed in foliar development itself: or it may appear internally in the complicated segregation of the vascular tracts in plants where cambium is absent or sluggish, as in the ferns or Lycopods. Such influences of the size-factor have long been recognized by animal morphologists: they are now beginning to find their place in the morphology of plants. (*See* F. O. Bower, *Proc. Roy. Soc. Edin.*, vol. xli., xliii.)

Causal Morphology.—The influence of the size-factor may be offered as an example of causal morphology, that is, the relation of form to environmental influence. It must suffice here merely to mention those better known branches of its experimental study which deal with the relation of form to such influences as gravity and light. Hofmeister introduced experiment in this field in his *Allgemeine Morphologie der Gewächse* (1868) as a corrective to the idealistic morphology of the previous period. His observations dealing with the arrangement and final form of the parts constituting the shoot were the natural precursors of the later work of Sachs, who recognized that the form and manner of life of plants "must in great part have arisen through the perpetual operation of gravity and light." (*Vorlesungen, 2te Aufl:* p. 545.)

Adaptation.—The scalyness or succulence of isolated species or genera under xerophytic conditions may be taken as examples of protective adaptation. Such characters are often hereditary: for instance, the succulence of a cactus or of a spurge appears in the seedling, even when grown in moist air: a seedling parasite, such as the dodder, produces parasitic seedlings that require attachment to the host for full development. Here the germ cell carries the character held as adaptive. On the other hand many formal characters that are specially related to climate or soil may be less marked, or even absent in the offspring grown under medium conditions. They have not been permanently stamped upon the germ-cells. Such differences raise the general question of the inheritance of adaptive form.

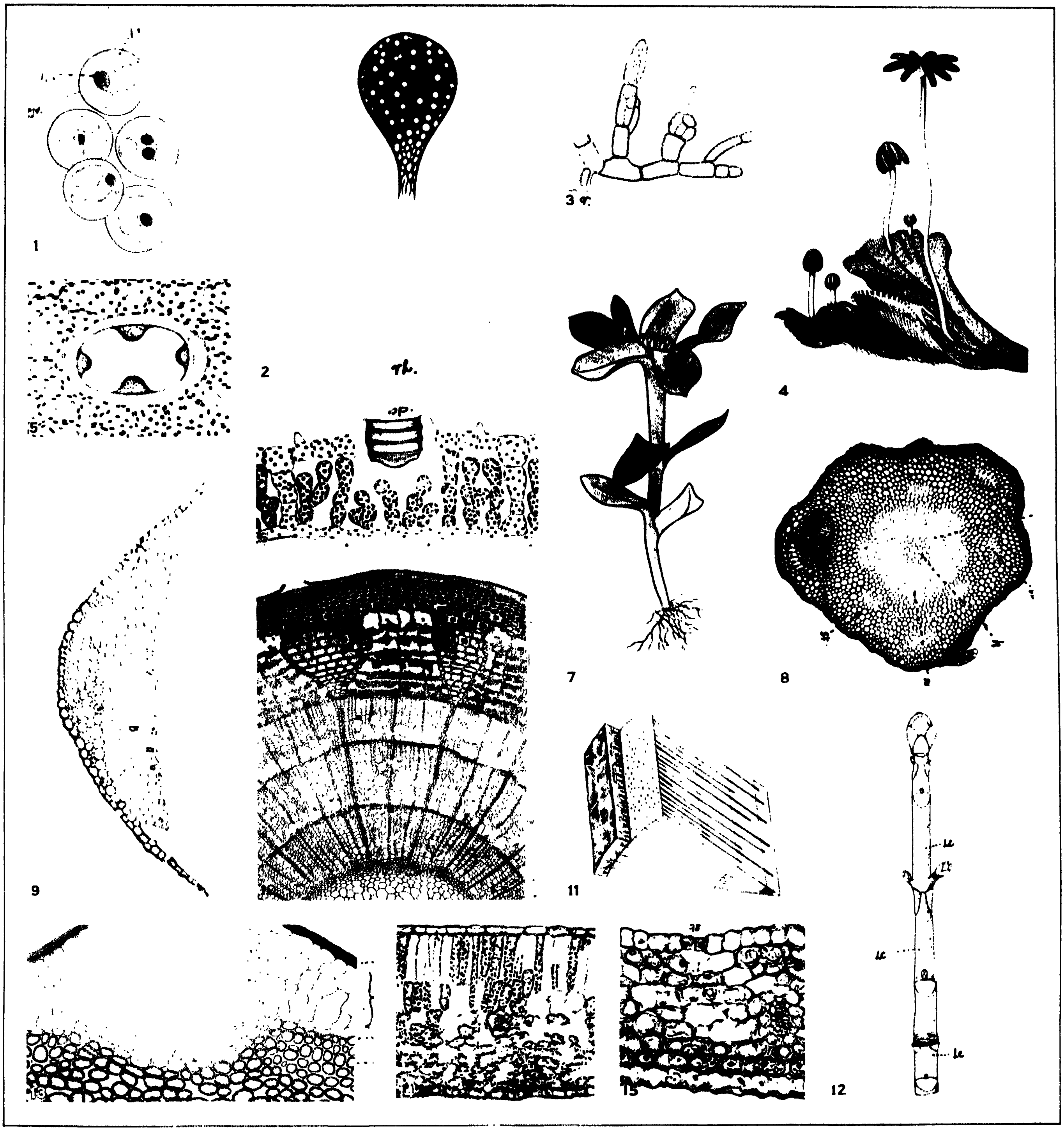
Inheritance of Adaptive Characters.—Direct experiments that adaptive or impressed characters may be inherited in plants have so far given indecisive or negative results. All such experiments necessarily range within the narrow limits of laboratory time. If, however, a sequence of events conducted with the latitude of geological time gives a positive result, it seems right to give such a positive conclusion precedence over observations limited to a brief period. More than one good case has recently been brought forward showing the establishment of an ontogenetic adjustment as a permanently inherited character, where a consecutive evolutionary sequence of steps in its appearance can be traced from early geological periods, and confirmed by comparison of living species and genera. (*See* F. O. Bower, *Ferns,* vol. iii., Cambridge, 1928.) The conclusion follows that, in plants at least, direct ontogenetic adjustments, if repeatedly imposed, may become hereditary. Other opinions are held on this point, especially by zoologists (*see* LAMARCKISM, HEREDITY). If such inheritance were wide-spread or general, an important factor would be supplied in explanation of the prevalent phenomenon of adaptation.

But it would not provide a full explanation. The nature of the organism is the more decisive factor in adaptation. It suggests a tendency of initiative in the organism itself, which would go far to explain certain broad features in evolution. Intensive study of the coherent class of the ferns has shown similar trends of advance in distinct phyla-parallel changes which constitute together a positive phyletic drift. This may be held as determined by the "nature of the organism": and to it, acting on differences in that nature, may be attributed the results which we see worked out in those distinct classes and divisions of the vegetable kingdom, which nevertheless may have evolved under conditions essentially alike.

A frequent consequence of homoplastic adaptation is *convergent evolution,* with a high degree of similarity, or even of *standardization* as the final result. Examples of this are frequent in the vegetative system: for instance, in the phyllodes of *Acacia* and *Oxalis,* and the xerophytic leafage of *Veronica* and *Cupressus:* also in the prevalence of trimerous and pentamerous flowers. But it is in the propagative organs that it is most remarkable, leading to the high uniformity of the archegonia seen throughout the higher cryptogams, of the megaspores of the heterosporous types, and of the embryo-sacs in Angiosperms. Such standardization of parts, which can hardly have been in any of these examples strictly homogenetic, greatly increases the difficulty of their phylogenetic treatment, so far as it is based upon features apparently so similar.

Alternation of Generations.—A few examples must suffice in illustration of the working out of the principles thus underlying the more recent developments of plant-morphology. The first is the phenomenon of *Alternation of Generations.* In mosses and ferns the life-history comprises two distinct phases, or generations, which appear in alternate succession. In the ferns the one is the leafy *fern-plant,* which as it bears sporangia containing spores, is called the *sporophyte:* the other is a small green scale, the *prothallus,* which bears the sexual organs, or gametangia, containing the gametes, known as the spermatozoid, and ovum or egg: it is therefore called the *gametophyte.* These alternate generations together constitute a life-cycle of two somatic stages, each limited by a unicellular state, for each spore may germinate to form a prothallus, and each fertilized egg may grow into a new fern-plant (*see* PTERIDOPHYTA). Such a cycle exists in the life-history of all mosses and ferns, while its correlative stages appear also in modified form in seed-plants: moreover it is now proved that a like alternation exists also in many Algae and Fungi. *In fact an alternating cycle, with varying proportion of somatic development, underlies the morphology of all plants that possess sexuality.*

Strasburger (1897) related this cycle with the cytological state of the respective stages (*see* CYTOLOGY). Since in fertilization (*syngamy*) the number of chromosomes is doubled, the generation that springs from it is (2x) *diploid* (*e.g.*, fern-plant, moss sporogonium): in the tetrad-division that precedes spore-formation, a corresponding reduction (*meiosis*) is effected, and the generation that springs from the spore is (x) *haploid* (*e.g.*, fern-prothallus,



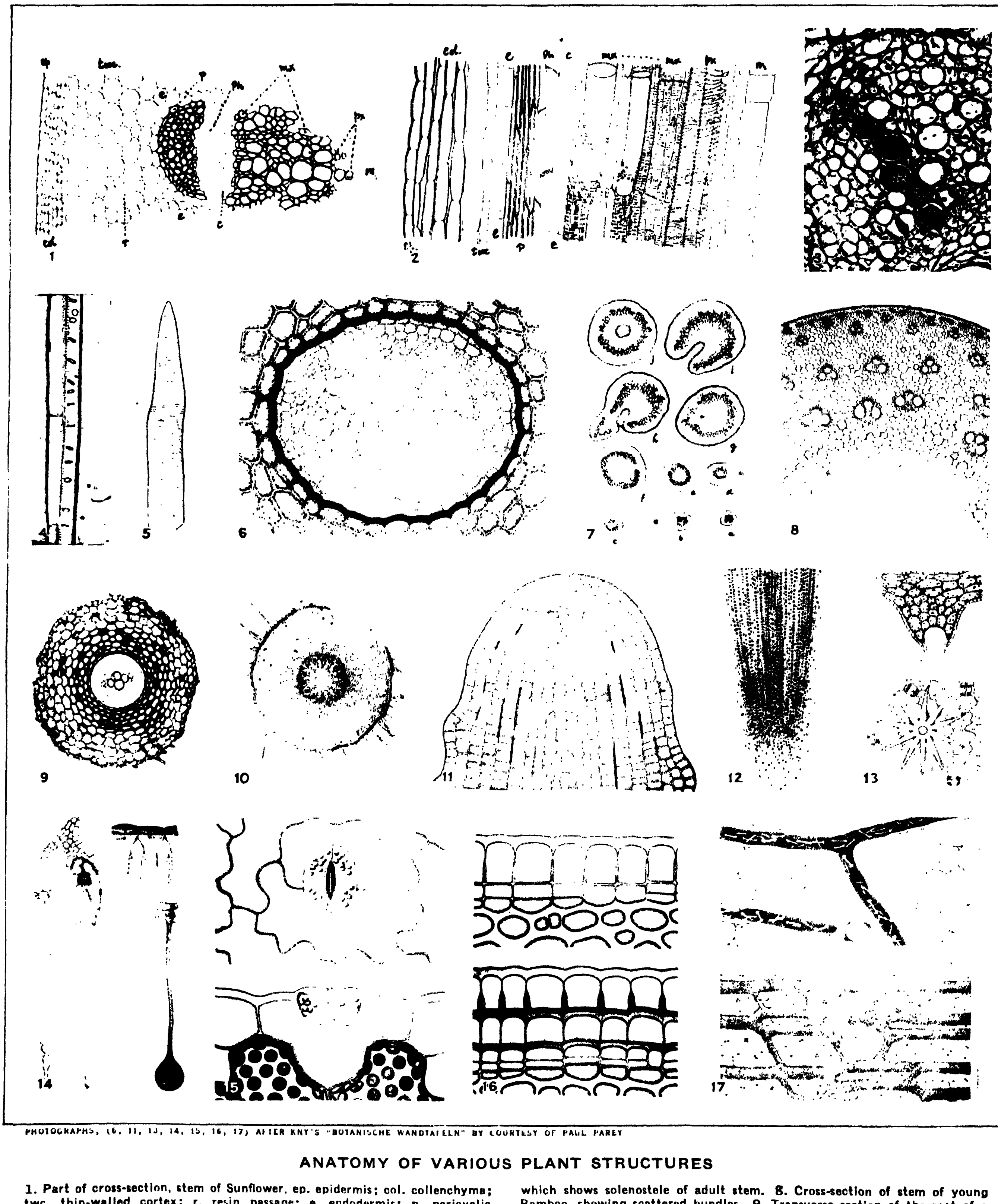
BY COURTESY OF (2-6, 10, 13) PAUL PAREY, FROM KNY, "BOTANISCHE WANDTAFELN"

EXAMPLES OF THE DIFFERENTIATION OF PLANT CELLS

1. Group of individuals of the unicellular Green Alga (*Chroococus*), one of which is in a state of division, as an example of an undifferentiated autonomous assimilating cell. (n.) nucleus; (chl.) chloroplasts; (pr.) cell protoplasm; (c.w.) cell-wall. 2. Plant of the primitive Siphoneus Green Alga (*Botridium granulatum*). The cell sends colourless tublets (rhizoids, rh.) into the mud on which it grows. The upper part contains the chloroplast. 3. Portion of a plant of a multicellular Red Alga (*Lejolisia mediterranea*). The upper branches are reproductive, and a basal cell is expanded as a special holdfast (r.). 4. Portion of a fertile plant of the Liverworth (*Marchantia polymorpha*), with numerous rhizoids, lower surface. 5. Surface view of a breathing pore of *Marchantia polymorpha*. 6. Section of the upper layers of the body of a mature plant of *Marchantia polymorpha*. (b.p.) breathing pore. 7. Male plant of the Moss (*Funaria hygrometrica*), with basal rhizoids. 8. Transverse section of the aerial stem of the Moss (*Polytrichum commune*); (h) hydrom, (l) leptom, (am) amylon, (st) sterom, (lt) leaftrace. 9. Transverse section of "leaf" of *Polytrichum commune*, showing photo-synthetic plates attached to the upper surface. 10. Portion of a transverse section of a stem of the common Lime (*Tilia europea*), showing three annual rings and peripheral cork. 11. Plan of construction of a Lime stem after four years of secondary thickening. The medullary rays are represented by black lines in the radial and transverse views, and by black dots on the exposed tangential wood surface. 12. Twig of the Horse Chestnut (*Aesculus Hippocastanum*), with lenticels (lc). 13. Transverse section of a lenticel and subjacent cortex, from the stem of the Elder (*Sambucus nigra*). 14. A dorsiventral leaf. Portion of a transverse section of the leaf-blade of the Privet (*Ligustrum*), showing upper palisade and lower spongy tissue. 15. An isobilateral leaf. Portion of a transverse section of the leaf-blade of the Iris, showing a stoma of the lower surface (near centre, upper margin of picture), and no differentiation of palisade tissue

PLATE II

PLANTS



PHOTOGRAPHS, (6, 11, 13, 14, 15, 16, 17) AFTER KNY'S "BOTANISCHE WANDTAFELN" BY COURTESY OF PAUL PAREY

ANATOMY OF VARIOUS PLANT STRUCTURES

1. Part of cross-section, stem of Sunflower. ep. epidermis; col. collenchyma; twc. thin-walled cortex; r. resin passage; e. endodermis; p. pericyclic fibres; ph. phloem; c. cambium; mx. metaxylem; m. medulla. 2. Radial longitudinal section, same stem. (Lettering as in fig. 1.) 3. Cross-section of phloem of stem of Cucumber, showing four sieve plates. 4. Longitudinal section of the wood of a stem bundle of Maize plant, showing reticulately pitted, spiral and annular vessels. 5. Part of a Fern tracheid, with pointed end and scalariform pits. 6. Cross-section of a vascular bundle from the leaf-stalk of a Fern. 7. Sections of the stele of a Fern (*Loxsoma*), from the juvenile to the adult stem: (a) solid protostele; (b) medullated protostele; (c) and (d) medullated protostele with inner phloem; (e) and (f) widening of the phloem cylinder; (g) and (h) pocket of inner endodermis [illegible] outer endodermis at a leaf gap; (i) a transitional state to (j), which shows solenostele of adult stem. 8. Cross-section of stem of young Bamboo, showing scattered bundles. 9. Transverse section of the root of a Fern (*Pellaea*), with diarch xylem and sclerotic cortex. 10. Transverse section of the aerial root of *Vanilla*, with polyarch xylem and numerous root hairs. 11. Radial longitudinal section, stem apex of an Angiospermic plant. 12. Radial longitudinal section, tip of root of the Onion, showing root cap. 13. Surface and sectional views of a stellate hair of an Angiosperm. 14. Examples of forms of hairs of Angiosperms. 15. Surface and sectional view, stoma from leaf of an Angiosperm. 16. Stages in formation of cork and phelloderm as seen in cross-section of an Angiospermic stem: (Upper) the first division of the sub-epidermal phellogen; (Lower) the completion of a layer of cork. 17. (Upper) Part of a Laticiferous Cell from the stem of a *Euphorbia*, containing bone-shaped starch grains;

moss-plant). It is a morphological problem of the first rank to determine the evolutionary relation of these generations to one another, whether in the individual, the phylum, or in plants at large.

Whatever the historical origin of alternation may have been, certain features in its further development were probably as follows. The land-habit of the Archegoniatae appears to have encouraged or fixed a biological difference between the generations: the gametophyte is characteristically semi-aquatic, while sexuality which is its end depends upon external liquid water: the sporophyte is characteristically a land-living body, often rooted in the soil, while the dissemination of the spores depends normally on dry conditions. Thus the alternate generations of the Archegoniatae accord well with an amphibial life, one being distinctly sub-aerial, the other not fully freed from dependence on external water. But the tie of aquatic fertilization (zoidiogamic) is inconvenient for land-living organisms: hence it is no surprise to find that the higher flowering plants have broken loose from it, by adopting fertilization by a pollen-tube (siphonogamic). The gametophyte by successive steps of reduction loses its independence as a separate generation, while the sporophyte becomes dominant. This state may be held as the last essential step in the adaptation of plant-life to a land-habit.

A second illustration of the working out of the principles summarised above may be taken from the leaf. Of all the vegetative organs the leaf raises questions most open to debate. In the older morphology an ideal leaf was envisaged, and other types of leaf were regarded as modifications of it. But the duty of an evolutionist is to look not to an idea, but to the facts supplied by the lower organisms. They show that, whether in the gametophyte or the sporophyte, a leafless state preceded foliar development. Moreover both fossils and living plants suggest that all leaf-like appendages did not spring from a common source, but polyphyletically.

The effect of such considerations is to relax the old rigid conception of "the leaf" as a morphological constant. Biologically a leafy shoot appears as a favourable advance on a simpler organization, bringing with it an increasing proportion of absorptive surface to bulk. The existence of a demand for this is common to enlarging organisms, and the foliar development appears as a consequence in any or all such. The facts indicate an independent response in many distinct phyletic lines, with the result that the leaves so produced would not be all homogenetic, but probably in high degree homoplastic.

Conclusions.—From the preceding sketch of current plant-morphology it is seen to be founded on the theory of evolution, used as a working hypothesis. Observed facts are interpreted from the point of view of phylesis, the argument leading towards the reconstitution of evolutionary history. The difference between the older idealistic and the newer inductive morphology has been well drawn by Sachs. He pointed out "that the former fits new facts into a scheme of old conceptions, the latter deduces new conceptions from new facts" (*History of Botany*, 1890). But morphologists are still bound by an idealistic evolution theory, for some preconceived type is in their minds. The remedy lies in a refusal to accept any conclusion from comparison as definitive, unless based upon consecutive data derived from actual organisms phyletically related one to another. The consequence of this would be a greatly increased recognition of polyphyletic sequences. But it is better to entertain a wide theory of polyphylesis, with that apparent indefiniteness of conclusion that follows in its train, than to accept questionable doctrines that bring satisfaction only to uncritical minds.

Finally there remains the question of causality. The causes of development can best be unravelled and their relations to the environment established by experiment. On the other hand, experiment by itself cannot reconstruct history: for it is impossible to rearrange for purposes of experiment all the conditions exactly as they were in an earlier evolutionary period: and even if this were done, can it be assumed that the subjects of experiment will really be the same? Consequently there must always be a margin of uncertainty whether a reaction observed under experiment to-day would be the exact reaction of a past age. Nevertheless there is a great future before experimental morphology: and though it cannot wholly unravel the history of form, this should still be approached experimentally as well as objectively.

Thus the way had already been prepared for Modern views, associated with "hormones," and their influence on individual development indicates from yet another angle how morphology is becoming ever more closely knit to physiology. It has been said that it deals with the stereotyped results of physiology. This is true in so far as it points towards the historical aspect of morphology, extending back as it does to the remotest fossil records: while physiology deals observationally with the reactions of the present time. But a better summing up of the relations of these two branches of biological science would be that morphology deals with all phenomena of form, including such as are not yet physiologically understood.

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ANATOMY OF PLANTS

The term "Anatomy," originally employed in biological science to denote a description of the facts of structure revealed on cutting up an organism, whether with or without the aid of lenses for the purposes of magnification, is restricted in the present article, in accordance with a common modern use, to those facts of internal structure not concerned with the constitution of the individual *cell* or structural unit of the plant body.

An account of the anatomy of plants naturally begins with the cell which is the proximate unit of organic structure. The cell is essentially an individualized mass of protoplasm, of small dimensions, and containing a differentiated protoplasmic body, called a *nucleus*. Other protoplasmic bodies, known as plastids, and inanimate matter, mainly in solution or suspension, are present. But all cells which are permanent tissue-elements of the plant body possess, in addition, a more or less rigid limiting membrane or *cell-wall*, consisting primarily of cellulose or some allied substance excreted by the living cell-body and serving to connect the different cells of a tissue (*see* below). Upon the characters of constitution, thickness and sculpture of the cell-walls the qualities of a plant-tissue largely depend. The life of all the cells in a plant-body may be prolonged or a number of the cells may die and their protoplasm be removed. Thus a tissue may consist of living encysted units combined with an inanimate framework of cell-walls, enclosing in their cavities solely liquids and gases. In such cases the characters of the adult tissue largely depend on the proportion and distribution, the stature, form and contents of the living and dead units, and on the nature of their walls. It is customary in plant anatomy to speak of the cell-wall with its enclosed cavity as "the cell," and of the contained protoplasm or other substances as *cell-contents*.

In all but the simplest forms the plant-body is composed of a number of cells associated in more or less definite ways. In the higher or more complicated plants the cells come to differ greatly among themselves so that the adult body is composed of definite systems of units. Each system has its own characteristic structure, depending partly on the characters of the component cells and partly on the method of association. Such a system is called a *tissue-system*, the word tissue being employed for any collection of cells with common developmental, functional or structural characters to which it may be conveniently applied, and accepted by the general resemblance which was thought to exist between the texture of plant-substance and that of a textile fabric before the fundamental constitution of plant-substance was discovered.

It is convenient here to define the two chief types of cell-form which characterize the tissues of the higher plants. The term *parenchyma* is applied to tissues the cells of which are isodiametric or cylindrical in form. The term *prosenchyma* is applied to tissues consisting of long narrow cells with pointed ends

The reader is referred to special articles on the anatomy of the lower plants (Thallophyta: Algae and Fungi, and Bryophytes: mosses and liverworts) in which the differentiation of tissues is comparatively slight. It must suffice here to mention that both Algae and Fungi range from the simplest unicellular forms with no external differentiation of the body to forms of greater stature and complexity of organization. The progress in complexity is closely associated with division of physiological labour among the component cells and with the adaptation of the multicellular organism to the needs of its environment. But whatever are the various states attained by individual genera the majority of the cells of the adult bodies of both Algae and Fungi remain alive and the tissues are essentially parenchymatous.

In accordance with the greater complexity in the conditions of life on land for self-supporting plants, considerably more advanced tissue-differentiation is exhibited by the Bryophyta, which are mainly terrestrial plants. In a general way this greater complexity consists (1) in the restriction of regular absorption of water to those parts of the plant-body which are in close contact with the soil, and (2) in the more regular evaporation of water from the parts exposed to the air. It is, however, in the higher vascular plants that those two principles find their fuller expression, for in the bryophytes water is still absorbed, as, for example, from rain or dew, by the general plant-surface. The lowest liverworts have an extremely simple vegetative structure comparable to that of many of the simpler Algae, for as their bodies are small and normally live in damp air the demands of terrestrial life on them are at a minimum. Thus their bodies consist of true parenchyma, and the vast majority of the component cells remain alive. Rooting and absorbing thread-like cells (*rhizoids*) universally occur on their lower surfaces in contact with the soil, and considerable tissue-differentiation may occur within the body. Thus some possess a distinct assimilative system consisting of branched chains of thin-walled cells packed with green plastids (*chloroplasts*) and arising from the bases of large cavities directed towards their upper illuminated surfaces. These cavities are completely roofed by a layer of surface cells pierced by pores, surrounded by special cells, and through which aeration and evaporation are freely maintained. In certain forms in which the body consists of thick midribs and delicate lateral leaf-like appendages strands or bundles of long thick-walled fibre-like (*prosenchymatous*) cells with pointed ends run longitudinally through the midribs, which are devoid of special assimilative tissue. The walls of these cells are strongly lignified (*i.e.*, consist of woody substance) and are irregularly thick and thin so as to be closely studded by simple pits which are usually arranged in spirals running round the cells and often elongated in the direction of the spiral. There is much variety of detail in the differentiation of the tissues of the liverworts, but the general plan of construction resembles that adopted in the leaves of higher plants.

In the mosses the plant-body is generally more elaborate in accordance with its fuller commitment to terrestrial life. There is always a radially organized supporting and conducting axis (stem) bearing laterally throughout the greater part of its length thin, flat assimilating and transpiring appendages (leaves). To the base of the stem or to those parts in contact with the soil are attached branched rhizoids. In some cases the stem possesses a special surface or epidermal layer of cells, but usually all the outer layers of the stem are composed of brown, thick-walled, lignified, prosenchymatous, fibre-like cells forming a peripheral *stereom* (mechanical and supporting tissue) which forms the *outer cortex*. This passes gradually into the thinner-walled parenchyma of the *inner cortex*. The entire cortex is generally alive and its cells often contain reserve foods in the form of starch. The centre of the stem, in the forms which live on soil, is composed of a strand of narrow, elongated, thin-walled, unlignified, dead water-conducting cells (*hydroids*) which are seldom pitted. This hydrom strand has in most cases no connection with the leaves, but runs straight up the stem and spreads out locally below the reproductive organs. In the aquatic and semi-aquatic forms, and in those mosses which live under conditions of extreme drought the entire plant-surface absorbs water, perpetually in the first two cases, and during rain in the third. In such forms the hydrom strand is either slightly developed or altogether absent. The leaves of most mosses are flat plates, each consisting of a single layer of square or oblong assimilating cells containing chloroplasts. The marginal cells of the plates are frequently produced as teeth and their walls are thick. The centre of the leaf is often occupied by a midrib consisting of several layers of parenchymatous cells elongated in the direction of the long axis of the leaf and poor in chloroplasts. This midrib may be considered a primitive conductive foliar strand or *leaf-bundle*. Associated with this conducting parenchyma are frequently found hydroids like those of the central strand of the stem, and in some cases continued into the cortex of the stem as a *leaf-trace bundle* (the anatomically demonstrable *trace* of the leaf in the stem). In several cases the leaf-trace runs vertically downwards for some distance in the outer cortex and ends blindly in a fan-shaped expansion: in others it joins the central hydrom strand so that a connected water-conducting system is established between stem and leaf.

Further differentiation of tissues characterizes the highest family of mosses, the Polytrichaceae. In these elongated, living, nucleated cells with a thin lining of protoplasm surround the dead hydrom, and form the *leptom*, inferred to serve for the conduction of organic substances, since the entire cavity of a leptom cell is sometimes occupied by proteid contents. The ends of each leptom cell are slightly swollen and fit to the similar swollen ends of the next leptoids in a row. The end walls are usually very thin, and the protoplasm, on artificial contraction, commonly sticks to them though no perforations of the walls have been found. It is considered that these cells are in some measure comparable to the *sieve-tubes* of higher plants (*see* below). Associated with the leptoids are similar cells without swollen ends and with thick end walls, while between the hydrom and leptom is a cylinder of cell-layers, known as *amylon*, which may serve for the temporary reservation and in the distribution of carbohydrates, since they sometimes contain an abundance of starch. The underground portion of the stem (*rhizome*) bears rhizoids and simple scales. The aerial parts bear leaves, each with a simple midrib several cells thick with a strong band of stereom above and below a bundle of leptom, hydrom and amylon cells which join the central cylinder of the stem. Each midrib bears two wings, one cell thick, while above the midrib is a series of closely set, vertical, longitudinally-running plates of green assimilative cells.

Vascular Plants.—It is, however, in the higher vascular plants (Pteridophyta, *e.g.*, ferns, horse-tails, club-mosses and Phanerogama or flowering plants) that the greatest anatomical complexity is found, for these are the dominant land plants. Such plants are not exactly comparable with the bryophytes for while the body of the latter bears the sexual organs and is called a *gametophyte*, and later nourishes a simple spore-bearing body (*sporophyte*), the vascular plant is a sporophyte which later nourishes a simple and reduced gametophyte. Nevertheless the gametophytic bryophyte and the sporophytic vascular plant have similar physiological needs and are both fixed to the soil. The chief new feature in external conformation of the body of a vascular plant compared with that of a bryophyte is the presence of "true" roots, the first formed of which is a downward prolongation of the primary axis of the plant. From this and from various parts of the shoot-system other roots originate. The roots of Pteridophytes are structurally simple and uniform compared with those of Phanerogams, but all manifest a primary plan of construction in direct relation to their normally subterranean life and fixative and absorptive functions; they differ from aerial stems in the characters of their surface tissues, in the absence of the green assimilative pigment chlorophyll, in the arrangement of their vascular systems, and in their mode of apical growth. Great variety in stem- and leaf-form and structure is shown by the vascular plants.

But in spite of the many considerable differences of detail between Pteridophytes and Phanerogams, we can trace, alike in root, stem and leaf a threefold division of tissue systems, already indicated among the bryophytes, and expressive of the fundamental conditions of evolution of the bulky body of a land plant. Thus there is (1) a specialization of a surface layer of cells which regulates the immediate relations of the plant with its surroundings, while varying in expression in the subterranean and aerial parts. In the former the surface layer is pre-eminently absorptive and in the latter protective provision at the same time being made for the gaseous interchange of oxygen and carbon dioxide involved in respiration, and for such vital functions as assimilation and transpiration. This surface layer is known as the *epidermis.* On the other hand we have (2) an internal differentiation of conductive tissue, prefigured in the bryophytes, and collectively known in the vascular plants as the *vascular system.* The remaining tissue of the plant-body, which shows varied local differentiation and is concerned with special functions, is known by reason of its peripheral position in relation to the central conductive tissue as (3) the *cortex.* But besides absorption, assimilation, conduction and protection, provision is made for *support* and the *storage of food.* Thus locally in the cortex and vascular system special supporting tissues (stereom) may be developed according to the varied needs and the conditions of body-differentiation, and living cells of both the cortex and the vascular system may serve for temporary storage of foods and are specialized accordingly. The functions of aeration, assimilation and transpiration, by which the bulky tissues of the plant-body obtain oxygen for breathing and carbon dioxide for food-manufacture, and the removal of excess water is assured, are maintained by an extensive system of *intercellular spaces* communicating with the external air.

Epidermis.—The epidermis of the subaerial stems and leaves is primarily protective and usually consists of a single layer of living cells devoid of chloroplasts, and with thickened and cuticularized outer walls, defensive to slight shock and small parasites, but permitting controlled evaporation. At intervals it is interrupted by small pores (*stomata*) leading from the outer air to the system of cortical intercellular spaces, and serving for gaseous interchange between the primary tissues and the outer air. Each stoma is surrounded by a pair of peculiarly modified epidermal cells called *guard cells* which possess chlorophyll and open and close the pore, especially in accordance with the conditions of transpiration. The stomata of leaves are often situated at the bottom of pits in the leaf-surface. Thus transpiration is checked by the creation of a still atmosphere in the pit above the pore. Such an arrangement of the stomata is found especially in plants which require to economize their water supply if transpiration is in excess of absorption. In many plants living in conditions which tend to promote excessive transpiration at certain hours of the day, the epidermis is doubled or trebled and forms a *water tissue* which supplies the immediate needs of transpiration, and prevents the injury which would result in the epidermis if its cells were excessively depleted.

Hairs and Scales.—The epidermis of many species of vascular plants bears hairs or scales of varied form and function. Hairs are characteristic of stems and leaves of primitive pteridophytes and of many flowering plants, while scales characterize such pteridophytes as the advanced ferns. The simplest hairs consist of single elongated cells projecting above the general surface of the epidermis, while others consist of simple or branched cell-chains. The more complex scales are flat plates of cells commonly inserted on mounds or stalks, and may be placed parallel to the leaf-surface or projecting directly from it. By such emergencies transpiration is diminished by the stillness of the atmosphere between them. In other instances the hairs are glandular and excrete ethereal oils which tend to reduce transpiration, or they may be stinging, as in the common stinging nettle, in which the top of the hair is brittle, and when broken penetrates the skin and injects formic acid into the slight wound thus formed. In many cases both hairs and scales are shed before the stems and leaves are mature: in others they are retained throughout the life of the plant.

Hydathodes.—In many vascular plants special epidermal organs, known as *hydathodes,* are developed, especially on foliage leaves, and serve for the excretion of water in liquid form when transpiration is diminished so that the pressure in the water-channels of the plant has come to exceed a certain limit. Hydathodes are widely distributed in plants in certain tropical climates under which active root-absorption continues while the air is nearly saturated with water-vapour. In some cases the hydathodes are specially modified single epidermal cells or are multicellular hairs without direct connection with the vascular system. The cells concerned, like all excreting organs, have abundant protoplasm and large nuclei, and in many cases part of the cell-wall is perforated and resembles a filter. In others the hydathodes are associated with the ends of conductive strands and consist of groups of richly protoplasmic cells, as in the leaves of many ferns, while in flowering plants the hydathodes are most commonly directly connected with subjacent water-collecting cells known as *epithem* which act as intermediaries for the hydathodes and conductive strands. To illustrate, water expelled through hydathodes is often observable on the tips of grass leaves on a summer's evening and is commonly confounded with dew. Its expulsion as droplets is, however, due to the more rapid cooling of the air than of the soil as night approaches. Thus while active absorption continues by the roots, transpiration by the leaves is reduced in the evening and the conductive strands are overcharged with water which is expelled by the hydathodes. There are many other types of glands such as *nectaries, digestive-glands, resin-* and *mucilage-glands,* serving the most varied purposes in plant-life. Some involve epidermal cells, while others are more deeply seated, but as they are not involved in the primary activities of the epidermis they are here passed over. It will, however, be apparent that the epidermis of the stem and leaf of a vascular plant may be highly specialized.

Epidermis of Root.—The epidermis of the root is fundamentally different from that of the stem or the leaf. In relation to its normal function of water-absorption its cell-walls are not cuticularized and usually remain thin. The absorbing surface is increased by many of the cells being produced into tortuous, delicate, unicellular tubes (*root-hairs*) which aid in anchoring the root, and readily absorb the surface films of water from the soil particles. A root-hair thus corresponds in function with a rhizoid of a bryophyte. The hairs are normally definitely restricted to a more or less definite zone of the root a little removed from the growing *root-tip.* At the lower limit of this zone hairs are constantly being formed as the root advances in the soil, while at the upper limit they have passed maturity, are dying and are being destroyed. Thus beyond the zone which at any moment bears living absorbing hairs (the *piliferous zone*) the epidermis is extensively or completely destroyed, and its place is taken by the immediately subjacent cortical layer, which is not absorptive, but becomes protective like the epidermis of the stem or leaf. At the apex of the root, covering and protecting the delicate tissue of the growing point, is a special *root-cap,* consisting of a number of layers of cells produced by continual active local division of the apical epidermal cells, and which break down into mucilaginous products towards the outer surface of the cap, thus facilitating the passage of the apex as it pushes between the soil particles, and keeping the apex continually moist.

The Cortex.—The cortex consists primarily of living parenchyma, but its differentiation may be extremely varied, and in the complex bodies of vascular plants its functions are varied and may be modified. The cortex of a young stem is usually green as its cells possess chloroplasts, and a fine system of intercellular spaces communicates with the external air through stomata. With age the inner cortical layers may lose their chlorophyll and become storage tissue, and the outer layers may be extensively modified (*see* p. 10, *secondary tissues*). In many pteridophytes (*e.g.,* ferns) the mature outer cortical layers of the stem and root are hard *sclerenchyma* with thick brown walls, but in flowering plants, while the stems are still slender, the cells of the outer cortical layers elongate and become cylindrical so that their intercellular spaces are widened. Vertical bands of cellulose thicken those regions of the walls which are in contact with the intercellular spaces, but the remaining regions of the walls usually remain thin. Such a tissue is known as *collenchyma.* It provides peripheral support for the growing stem, and as its cells are alive, is open to later modifications with changing needs in stems which undergo annual increase in girth. The wonderful recovery, after bending and stretching, which is often observable in herbaceous stems, is in large measure due to the effective distribution of this elastic collenchyma. On the other hand sclerenchyma is commonly dead and provides a more rigid but usually unmodifiable supporting tissue. Its adequacy will be evident for stems such as those of modern ferns which do not increase annually in girth. Less commonly, scattered cells or cell-groups which increase little in length may become *stone cells,* with irregularly but inordinately thickened hard walls, while in some cases longitudinal rows of cells disintegrate thus forming canals, such as *resin canals,* the cortical wall-cells of which are excretory. Many such minor modifications of the original cortex of the stem occur in association with special localized functions.

Phloeotherma.—The innermost layer of the living cortex investing the central cylinder of the stem is, however, often early and peculiarly modified as a continuous cylinder called the *phloeotherma.* Throughout its entire course its cell-walls remain in close contact so that the system of intercellular spaces in the cortex is not continued into the central cylinder of conductive tissue. Towards the upper limit of the phloeothermal cylinder, while the stem is still young, the component cells may be rich in plastids in which starch grains are formed. In some localities the phloeotherma is known as a *starch sheath,* which is variously thought to play some rôle in the controlled conduction of carbohydrates from the assimilatory cortical cells to the vascular cylinder, or in some connection with the directional growth of the young stem. In the more mature regions of the stem starch grains are absent from the phloeothermal cells, the walls of which are somewhat thickened. In particular, a band of the lateral longitudinal and of the end walls is modified, being impregnated with a fatty substance which is thought to prevent radial transfer of foods in solution athwart the phloeotherma save under protoplasmic control of its cells. The phloeotherma is here known as an *endodermis,* and is thought to serve as a physiological barrier between the cortex and the central conductive cylinder.

Mesophyll.—The cortex of the leaf is primarily concerned with the primitive fundamental function of carbon assimilation, and to the active performance of this function the maximum exposure of living parenchymatous tissue containing chloroplasts is necessary. Thus the cortex of the leaf is essentially a green expanse of thin-walled parenchyma, known as the *mesophyll,* and is penetrated by a large and elaborate system of intercellular spaces which serve at one and the same time for the promotion of transpiration and respiration. The pathways for the gases which thus pass between the mesophyll and the outer air are the stomata, which in land plants with dorsiventral leaves are mainly or exclusively placed on the lower leaf-surface. By this means over-transpiration tends to be avoided, since the liberated water-vapour, being lighter than air, tends to remain in contact with the lower leaf-surface and checks evaporation. The stomata are in direct communication with the ample system of intercellular spaces in the mesophyll, the lower layers of which are commonly loosely arranged as *spongy tissue* with extensive intercellular spaces. This is the main transpiring tissue of the leaf, and in it chloroplasts may be comparatively few. It is protected from direct illumination and is at the same time liable to over-evaporation. The main assimilating tissue, on the other hand, is under the upper epidermis, is well illuminated, its cells are densely packed with chloroplasts, and are commonly oblong with their long axes perpendicular to the leaf-surface. The intercellular spaces are here narrow as between sticks in a bundle, and are in open communication with the spaces in the spongy tissue below. By reason of its resemblance to the boards in a fence, when viewed in a transverse section of the leaf, this portion of the mesophyll is called the *palisade tissue.* Leaves with blades held in a vertical position commonly possess palisade tissue on both sides or have little or no distinction in the form and arrangement of the cells of the mesophyll, since there is no difference in the illumination or other external conditions, while cylindrical or approximately cylindrical leaves may have palisade tissue all round. The leaves of shade plants have little or no differentiation of the palisade tissue. In fleshy leaves, which contain a great bulk of tissue in relation to their chlorophyll content, the central mesophyll contains little or no chlorophyll and may consist of water-storage tissue, while locally a layer or mass of sub-epidermal cells may be thick-walled and fibrous.

The cortex of the leaf-stalk is transitional in structure to that of the stem and leaf-blade. The leaf-stalk is traversed by one or more vascular strands connected below to the central conductive system of the stem, and leading forward in the leaf-blade to a complex system of minor strands which ramify the mesophyll and run their course in the plane of junction of the spongy and palisade tissue. The layer of mesophyll immediately investing each bundle is phloeotherma and usually takes the form of a special parenchymatous sheath of elongated cells, distinguished otherwise from the rest of the mesophyll only by their poverty in chloroplasts. In a few rare cases the phloeothermal cells are rich in chlorophyll. These *bundle-sheaths* are considered important in the conduction of carbohydrates from the assimilative cells to the conductive strands and in the supply of water from the latter for transpiration. Their function is thus considered in some measure comparable with that of the phloeotherma of the stem.

The cortex of the roots of Pteridophytes is commonly extensively sclerotic at maturity, but in flowering plants the root-cortex generally remains a living parenchymatous food-storing tissue. Its innermost layer is invariably an endodermis.

VASCULAR SYSTEM

Among the most striking characters of Pteridophytes and Phanerogams is the possession of a double (hydrom-leptom) conducting system, such as has been noted in the higher mosses, but with more sharply defined and specialized features. This is the *vascular system,* and associated with it are other tissues consisting of parenchyma and special stereom. The whole tissue-system is known as the *stelar system* (from the way in which in its simpler forms it runs through the whole axis of the plant as a column). When it is remembered that the moss plant is a gametophyte while the vascular plant is a sporophyte it will be realized that the vascular system of the latter is not the result of elaboration of the conductive system of the former, but that these vascular systems are most readily interpreted as somewhat similar products of differentiation in plants fitted for life on land.

Tissue Elements.—The hydroid of a Pteridophyte (*e.g.,* a fern) is initially a living undifferentiated parenchymatous cell. As it dies it usually elongates and its wall is irregularly thickened and becomes woody (lignified). Its contents at maturity are watery solutions and air. The thickenings are on the inner wall-surface, are insufficient to line the wall entirely, and take the form of a spiral or complex network. The mature hydroid is called a *tracheid.* Its end walls persist and are commonly oblique. When the walls are mainly thickened their unthickened portions are called *pits,* and according to the varied distribution of the thickenings, the size, form, number and distribution of the pits depend. Thus in *spiral tracheids* a broad spiral band of unthickened wall persists, while when the thickenings on a wall-face are more or less transverse bars (often joined by short vertical bars) there is a resemblance to the rungs of a ladder, and we have a *scalariform tracheid.* All manner of transitions from spiral to scalariform tracheids may be found in a single plant. Spiral thickening is, however, characteristic of tracheids in which lignification begins and is completed while elongation of the cell is still in progress. Scalariform thickening is typical of tracheids which mature late or slowly, so that thickening may be continued after elongation is completed. The pits of scalariform tracheids are typically *bordered pits,* as the bars of thickening last deposited are widest. The pits on tracheid-walls which are in contact with each other are at similar levels so that at regular intervals the cavities of contiguous tracheids are only separated by a common thin area of wall (the *pit-membrane*). Sooner or later the pit-membrane disappears so that the mature tracheids come to consist of a framework of lignified bars with numerous small open communications between the cell cavities. Collectively with associated parenchyma the tracheids constitute the ***xylem*** or ***wood.***

The leptoid of a Pteridophyte is also an elongated cell. It, however, remains alive, its wall is unlignified, it has a thin lining of protoplasm, but is destitute of a nucleus. It is always in communication with its neighbouring cells in a leptom strand by exceedingly minute wall perforations through which protoplasmic continuity is maintained. It is generally supposed that through these perforations organic substances are passed from cell to cell as through a sieve. The cells are accordingly called *sieve-tubes,* and collectively with associated parenchyma constitute the tissue called the *phloem,* or *bast.* The phloem is typically distributed at the periphery of the xylem when the latter is massed centrally, but may occur in other positions (*see* below). Between the phloem and the phloeotherma is a mantle of one or more layers of parenchyma forming the pericycle.

Arrangement of the Vascular System.—In vascular plants the xylem and phloem are nearly always found in close association in strands or *bundles,* but as is to be expected in so complex and varied a group as the Pteridophytes the arrangement of such bundles is by no means stereotyped either in the group or in the different parts or members of the plant-body. A connected vascular system runs, however, through the entire body. In the roots and leaf-blades the vascular system is comparatively simple. In the former a solid, slender xylem core is virtually invested by phloem, with a single layer of pericycle as a mantle in direct contact with a continuous cylindrical endodermis, beyond which is the bulky and often sclerotic cortex. The arrangement is thus virtually radial. The bundles in the leaf-blade are on a somewhat similar plane of simplicity, but their phloem is directed downwards, their xylem upwards, the tracheids are dominantly spirally thickened, and the phloem is scanty or entirely absent towards the slender bundle-endings. Similarly throughout the entire length of stem there may be a solid xylem core, surrounded successively by phloem, pericycle and endodermis. Such a vascular system is a *solid protostele.* The slender stems of most juvenile Pteridophytes are protostelic and despite widening of the *stele* in the more bulky portions of the adult plant, this primitive protostelic state may be maintained throughout the entire stem. In many cases, however, as in advanced ferns, the vascular system of the juvenile stem alone is a solid protostele. When followed upwards the core of the xylem strand may remain entirely parenchymatous. This parenchymatous core is the *medulla* or *pith,* and the stele is here called a *medullated protostele.* At higher levels the stem may show a different vascular arrangement, sieve tubes being differentiated in the centre of the medulla, at first as a solid strand, but later or higher as a cylinder with parenchymatous pith at its core and parenchyma between it and the xylem. At a still higher level there may be an inner endodermis between the pith and the inner phloem so that the succession of tissues from within as viewed in a transverse section of the stem may be medulla, inner endodermis, parenchyma (or inner pericycle), inner phloem, parenchyma, xylem, parenchyma, outer phloem, outer pericycle and outer endodermis. Such a local arrangement of the stelar elements is said to be *siphonostelic,* is considered an evolutionary advance on the protostelic state, and may characterize the entire upper portion of the adult stem.

When the vascular system is entirely protostelic the decurrent bundles from the leaves join the vascular system of the stem without disturbing the continuity of the latter. Thus throughout the entire plant the endodermis is an unbroken mantle. But in the siphonostelic portions of the vascular system of the stem, the pith and cortex are commonly in open parenchymatous connection through *gaps* in the stele, and round the edges of these gaps the inner and outer endodermal cylinders are united by endodermal cells. Thus here again the endodermis is a continuous tissue, and isolates completely the pith and the cortex from the vascular tissues. The gaps which occur immediately above the level of insertion of the leaf-trace bundles on the stele of the stem are called *foliar gaps,* while those which occur elsewhere are called *perforations.* When there is no overlapping of leaf-gaps the siphonostele is said to be *solenostelic;* when two or more leaf-gaps overlap, the stele is *dictyostelic.* Thus locally the vascular system of a Pteridophytic stem may be solenostelic or dictyostelic: likewise it may be locally a *perforated solenostele* or a *perforated dictyostele.* Rarely among ferns is there more than a single vascular cylinder. The condition is described as *polycyclic,* and an outer and inner cylinder may be even united by oblique lateral strands. In such cases the leaf-trace strands are joined to the outer cylinder, while the inner cylinder may best be considered concerned with internal conduction.

Structure of the Stele in Seed-plants.—The typical structure of the vascular cylinder of the adult primary stem of the Gymnosperms (firs and their allies) and Dicotyledons (the dominant group of higher flowering plants)—all of which are seed-bearing plants—is, like that of the higher ferns, a hollow cylinder of vascular tissue enclosing a central parenchymatous pith. But unlike the ferns the seed-plants have no internal phloem (except as a special development in certain families) and there is no internal endodermis. The xylem and phloem rarely form perfectly continuous layers as in the solenostelic ferns, for the vascular tissue is typically separated into distinct *collateral bundles,* the xylem of which is usually wedge-shaped in cross section with the first formed xylem (*protoxylem*) at the inner extremity, while the phloem forms a band on the outer side of the xylem, and is separated from the latter by a band of conjunctive tissue (*mesoderm*). These collateral bundles are separated from one another by bands of conjunctive tissue called *primary medullary rays,* which may be quite narrow or of considerable breadth.

When the pith is large-celled, the xylem of the bundles is often separated from it by a distinct layer of conjunctive tissue called the endocycle, and a similar layer, the *pericycle,* separates the phloem from the cortex. The inner layer of the cortex (phloeotherma) may form a well-marked *endodermis,* or may differ in other ways from the rest of the cortex. The pericycle, medullary rays, endocycle and mesoderm all form part of one tissue-system, the *external conjunctive.* The external conjunctive is usually a living and comparatively small-celled tissue, the cells of which are greatly elongated in the direction of the stem-axis and may be collenchymatous, sclerenchymatous, fibrous or food-storing. The conjunctive tissue of the stem is open to *secondary changes,* bound up with the thickening of the stem as it grows old. Most of the collateral bundles are leaf-trace bundles, *i.e.,* they can be traced upwards from any given point till they pass out of the cylinder, travel through the cortex of the stem, and enter the leaves. The remaining bundles (*compensation bundles*) which go to make up the cylinder, are united at some level with the leaf-trace bundles, and in turn form the traces of leaves at some higher level. Purely cauline vascular strands (*i.e.,* confined to the stem) are rare in the flowering plants, though common in Pteridophytes. The leaf-trace of any given leaf rarely consists of a single bundle only, the number of bundles in a trace is generally odd, and the median bundles of the trace are typically the largest.

Foliar- or *leaf-gaps* are formed in essentially the same way as in the ferns, but as the distribution of the bundles of a single trace may be wide and long, there may be a number of gaps in the cylinder associated with the insertion of the bundles of a single leaf-trace. The gaps are, however, often filled as they are formed by the development of external conjunctive tissue immediately above the points at which the bundles begin to bend out of the stele, so that sharply defined open gaps, such as occur in fern steles, are but rarely met with in flowering plants. The constitution of the stele of a flowering plant entirely from bundles as above described, which are either themselves leaf-traces or will form leaf-traces after junction with similar bundles, is the great characteristic of the stem-stele of flowering plants. These collateral bundles are obviously highly individualized. The external conjunctive tissue is often arranged in relation to each bundle separately, so that, for example, there may be pericyclic fibres immediately outside the phloem-masses alone. In some cases the individualization is carried further, the cortex and pith becoming continuous between the bundles, which appear as isolated strands embedded in a general ground tissue. Each bundle has its own investment of tissue corresponding with external conjunctive. The bundles sometimes keep their arrangement in a ring corresponding with the stele, though there may be no continuous cylinder. This condition is known as *astely.*

The Monocotyledons, one of the primary divisions of Angiosperms, typically possess large leaves with broad sheathing bases, containing numerous bundles. This results in the number of bundles present at any given level of the stem being high. These bundles are scattered in a definite though not superficially obvious order through the conjunctive tissue of the stele, which occupies nearly the whole diameter of the stem, the cortex being restricted to a very narrow layer, or scarcely recognizable as a definite zone. The mass of conjunctive tissue is developed as a large-celled ground-tissue, and around each bundle there is a fibrous investment. In the stems of many water plants various stages of reduction of the vascular system, especially of the xylem, are met with, and very often this reduction leads to the formation of a compact stele in which the individuality of the separate bundles may be suppressed, so that a closed cylinder of xylem surrounds the pith. The phloem is seldom so reduced, and there is normally a well-marked endodermis. In other cases the reduction goes much further till the endodermis comes to surround nothing but an intercellular channel, formed in place of the stelar tissue.

To the vascular tissue of the typical leaf and root of the Phanerogams reference is made below. But there are peculiarities of organization of the hydroids and leptoids of the bundles of flowering plants which here call for special mention. Generally the end walls of superimposed developing hydroids break down, so that the final product of differentiation is a continuous tube with lignified pitted walls. Such tubes are called *vessels,* and are characteristic of the vast majority of Phanerogams, though tracheids still dominate the Gymnosperms. There is every degree of transition between spirally thickened and reticulately thickened vessels. The sieve-tubes of Phanerogams in their most advanced forms which dominate the Angiosperms have the end walls or portions of the end walls specially perforated. Such walls are accordingly called *sieve-plates.* It is assumed that by such end sieve-plates the longitudinal movement of slimy foods is accelerated. Associated with the sieve-tubes are, in addition, cells of the same length as the sieve-tubes, generally narrow, thin walled and enucleate, and which are thought to co-operate in some intimate way with the sieve-tubes. They are known as *companion cells,* and a sieve-tube and its companion cell arise during tissue-differentiation from the same mother-cell. On the whole the leptoids and hydroids of the Phanerogams are considerably more specialized than those of the Pteridophytes.

Stelar Tissue of Leaf and Root.—In the leaf of the average Phanerogam the vascular tissue takes the form of a number of branching or approximately parallel, and usually anastomosing, strands, above and below which the mesophyll is raised so as to produce the so-called *veins.* The vein-system is typically very elaborate, and the bundle-system is concentrated in the leaf-stalk (*petiole*) as the tributaries of a river are massed in the main stream. The leaf-bundles are always collateral (the phloem being turned downwards and the xylem upwards), and the whole bundle may be protected above and below by fibrous cells. As the bundles are followed towards their blind endings in the mesophyll the fibres first disappear, the sieve-tubes are replaced by narrow elongated parenchyma which soon dies out, and the bundles usually end in short or long spiral or reticulate tracheids covered by the phloeothermic sheath.

The stele of the primary root of a Gymnosperm or Angiosperm is of radial structure. There are usually two or four xylem strands radially alternating with phloem strands (the stele being thus *diarch* or *tetrarch*), and the first formed xylem groups (*protoxylem*) are peripheral. A *polyarch* state is, however, common in *adventitious* roots (which arise on other stems or roots in "chance" positions), and the protoxylem groups are then numerous. The centre of the stele is seldom solid xylem, but is generally pithed, and sclerotic cells are by no means uncommon in the conjunctive tissue. The roots of some palms and orchids show a peculiar "polystelic" structure. Thus it will be seen that while the vascular systems of the stems of Phanerogams are highly individualized, those of the leaves and primary roots are of simpler organization, but are of varied structure.

Laticiferous Tissue.—There are, however, in certain families of Angiosperms peculiar tissues which are not met with in the Pteridophytes. Such, for example, is the *laticiferous tissue* found in Compositae and Euphorbiaceae, which takes the form of long, usually branched tubes which penetrate the other tissues of the plant in a general longitudinal direction. The tubes possess a delicate layer of protoplasm with numerous nuclei lining the walls, while the interior of the tube (corresponding with the cell-vacuole or cavity) contains a fluid called *latex,* consisting of an emulsion of fine granules and drops of very various substances, suspended in a watery medium, in which other substances (salts, sugars, rubber-producers, tannins, alkaloids and various enzymes) are dissolved. Of the suspended substances, grains of caoutchouc, drops of resin and oil, proteid crystals and starch grains may be mentioned. Of this varied mixture of substances some are undoubtedly *plastic* (*i.e.,* of use in constructing new plant tissue), while others are apparently end-products of metabolism, secreted within the plant-body. The relation of the laticiferous tissue to the assimilating cells, under which they often run, and the fact that where this tissue is richly developed the conducting parenchyma of the bundles, and sometimes also the sieve-tubes, are poorly developed, as well as various other facts, point to the conclusion that the laticiferous tissue has an important function in conducting plastic materials, in addition to acting as a reservoir for *excreta.* As a secondary function we may recognize, in certain cases, the power of closing wounds, which results from the rapid coagulation of latex in contact with the air. The use of certain plants as rubber-producers (notably *Hevea brasiliensis,* the Para rubber tree), depends on this property of coagulation. The trees are regularly tapped and the coagulated latex which exudes is collected and worked up into rubber. Opium is obtained from the latex of the opium poppy (*Papaver somniferum*) which contains the alkaloid morphine.

Laticiferous tissue is of two kinds: (1) *laticiferous cells,* which branch but do not anastomose, and the apices of which keep pace in their growth with the other tissues of the plant (Apocynaceae and most Euphorbiaceae), (2) *laticiferous vessels,* which are formed from rows of actively dividing (meristematic) cells. The end walls of these cells break down so that a network of laticiferous tubes arises (Papaveraceae, *Hevea*). In some cases, as in *Allium* and in the Convolvulaceae, rows of cells with latex-like contents occur, but the walls separating the individual cells do not break down.

Such facts serve to illustrate the advanced specialization of the higher plants compared with the land bryophytes, but by no means exhaust the anatomical peculiarities of the former. In particular, mention may be made of tissues which arise by modification of primary living tissues, and are accordingly known as *secondary tissues.*

CAMBIUM

Secondary Tissues.—In most of the modern Pteridophytes, Monocotyledons, and in annual plants among the Dicotyledons, there is no further growth of much structural importance after the tissues above considered have been differentiated. But in nearly all perennial Dicotyledons, and in all dicotyledonous and gymnospermous trees and shrubs, certain layers of cells retain the power of division, although they may be for long mature, and are apparently fixed elements of a tissue. By this power of growth and division they become the originators of new or *secondary tissues,* which bring in their train many modifications in the plant-body. Primary tissues which are thus awakened to new divisional activity become, like the growing points of stems and roots, *meristems* or the initials of tissues, but while the *apical meristems* of stems and roots give rise to the primary tissues above considered, these new meristems are *secondary meristems* since they give rise to secondary tissues. There are two chief secondary meristems, the *cambium* and the *phellogen.*

The cambium typically continues the formation of xylem and phloem, thus adding to the conductive tissue already produced. It is merely the cycle or band of parenchymatous tissue lying between the primary xylem and primary phloem. Its cell walls are generally thin, and as its cells enlarge by special nourishment, they are divided principally by tangential walls, thus producing radial rows of cells. The primary xylem remains stationary, but as the cell rows thus formed increase in number and the individual cells enlarge, the primary phloem and all the external tissues move outwards. The tracts of cambium between the strands of xylem and phloem are called *fascicular cambium,* while those which cross the primary medullary rays from bundle to bundle are called *interfascicular cambium.* The cells of the interfascicular cambium likewise divide mainly by tangential walls, and with the same frequency as the fascicular cambium. Thus radially within the interfascicular cambium the primary medullary rays are left stationary, while the surrounding tissue is pushed outwards. There is usually one cylindrical layer of actively dividing cells in the cambial cylinder, and it may be imagined that at any moment it has given rise by tangential division to two such layers. The products of the interfascicular cambium may first be considered. The inner products differentiate as parenchymatous cells which are added to the medullary rays; the outer products retain the power of division. Thus the cambium is moved slightly outwards and its cells divide as before by tangential walls into outer and inner layers. The inner layer thus formed differentiates as a parenchymatous addition to the medullary ray, and the outer layer retains the power of division. Thus a general outward movement of the cambium proceeds, leaving behind or within layers of cells which radially augment the medullary rays.

From time to time it is the outer layer of cells produced by cambial activity which becomes differentiated as parenchymatous cells, while the inner layer remains cambial. In this way the outward progress of the cambium is temporarily delayed but is not arrested. After a long period of cambial activity the interfascicular cambium has moved outwards to a considerable distance, having greatly augmented the medullary ray within and radially, and to a lesser extent, but also radially, without. It will be apparent that the interfascicular cambium is not a fixed or permanent layer of cells, but that the power of division is steadily transferred outwards, and the locus of the cambium is changed with time. It will be further evident that with each step in the outward movement of the cambium the circumference of the cambium must increase. The division of the cambial cells is accordingly not accomplished solely by tangential walls, but from time to time radial divisions also occur. Thus the cambial cylinder is widened and its integrity is maintained as it moves outwards. But while in the vast majority of higher plants the additions to the medullary rays thus produced are uniformly parenchymatous, and these *primary medullary rays* increase outwards as wedges, there is some complication in the products of cambial division between the primary xylem and phloem. The fascicular cambium is generally moved outwards with the same rapidity as the interfascicular cambium, so that the cylindrical form of the cambium is maintained.

Moreover, of the inner products of division in the fascicular cambium many differentiate as *segments of a vessel, tracheids, fibres* or *parenchyma,* which may be variously grouped, but which collectively constitute the *secondary xylem.* In many instances sooner or later one or more cambial cells, within which radially such elements have differentiated, produce exclusively radial rows of parenchyma. These rows have in general the characters of medullary rays, but are obviously purely of secondary origin, and continue neither inwards to the pith nor outwards to the cortex like the primary rays. They are indeed *secondary rays* of purely cambial origin. Of the outer products of division in the fascicular cambium many differentiate as *sieve-tubes* and *companion cells,* or as *fibres* or *parenchyma* arranged in various patterns and collectively constituting *secondary phloem.* With this tissue may also be associated minor *secondary rays,* reaching inwards to the cambium, often the direct radial continuations of similar rays in the xylem, but not reaching the cortex without. It will be apparent that the tangential dimension of each tract of fasicular cambium is steadily increased as the cambium moves outwards, so that the secondary wood increases as an outward widening wedge, while the secondary phloem appears as an inward widening wedge, the two wedges meeting at the cambium. It is not to be supposed that at any moment uniform behaviour is maintained by all the cambial cells in a longitudinal row, so that while at one level, and at various points in the fascicular cambium, secondary medullary rays are being formed in both xylem and phloem, immediately above and below this level, fibres, vessel-segments, sieve-tubes, wood-parenchyma and phloem-parenchyma are being produced. The secondary medullary rays are accordingly of no great depth, and may well be described as narrow bands of parenchyma placed radially in the xylem and phloem. Similarly the behaviour of the interfascicular cambium is not uniform at all levels or at all stages in its outward progress, for while for a time it may produce parenchyma exclusively, locally its products may be secondary phloem and secondary xylem. Thus after a time an island of secondary wood and phloem is seen in a cross section of the stem, dividing the primary ray into two branches, which, when followed outwards, reach the cortex. Nor are the primary rays of great depth, though on an average they are much deeper than the secondary rays, for the downward course of both xylem and phloem is tortuous, and fusion of strands occurs above and below the rays, which are accordingly of lenticular outline when seen in a tangential section of the stem.

Annual Rings.—In those plants whose annual activity is interrupted by a regular winter or dry season the limit of each year's increment of secondary wood, and to a less obvious degree of secondary bast, is marked by a more or less distinct line which is produced by the sharp contrast between the elements formed in the late summer of one year and those produced in the spring of the next. It is believed that in relation to the large and rapid supply of water and other substances to the unfolding leaves in spring and early summer, large vessels are produced by the cambium in the spring, while as summer advances and the need for water diminishes, the vessels formed are narrower, and as the supply diminishes still further, more abundant fibres, with greatly reduced cavities, arise. Thus in a single season of cambial activity a rough outward progression may be traced in the secondary wood of that season from wide vessels to narrow fibres, beyond which the transition to the wide vessels of the succeeding spring is sudden. Each zone thus recognized in a cross section of the stem is called an *annual ring,* and the lines of separation of successive rings mark the temporary halting places of the cambium at the end of successive seasons.

Sap-wood and Heart-wood.—The older wood of large trees, forming a cylinder in the centre of the trunk, frequently undergoes marked changes in character. The wood-parenchyma and medullary rays die, and the walls of all the cells often become greatly hardened, owing to the deposit in them of special substances. Wood thus altered is called *heart-wood* or *duramen,* as distinguished from the younger *sap-wood* or *alburnum,* which is nearer the cambium, carries on the active function of conduction, and retains its parenchymatous cells in life. The heart-wood ceases to be of any use to the tree except as a support, and owing to its dryness and hardness is much used for industrial purposes.

Phellogen and Periderm.—It will be obvious that secondary increase of xylem and phloem involves an outward movement of the primary phloem and of all the elements which surround the latter, and that the cortex, and particularly the epidermis, must accommodate for this movement, either yielding passively to a limit and being injured or destroyed by the outward pressure, or being to some extent modified so as to persist. In most cases the epidermis is unable to maintain the active radial division of its cells necessary for such expansion as occurs, is soon stretched to its limit, dies and is destroyed. Extensive radial division in the cortical cells is progressively less essential as the inner cortex is followed inwards, and as a rule, by a combination of radial and tangential divisions, the integrity of the cortex is maintained. Towards the periphery of the cortex, and commonly by modification of its outer layer, a secondary meristem, similar to the cambium, arises and produces external and internal secondary tissues. This meristem is the *phellogen,* and the whole of the tissue it gives rise to is known as *periderm.* The phellogen derives its name from the fact that its external product is the characteristic tissue known as *cork.* This consists typically of closely fitting layers of cells which quickly die, and when mature, have completely suberised walls which collectively serve to replace the epidermis as an external protective layer, when the former is ruptured. The outer layers of the cork are constantly being destroyed, but new layers are in progress of formation within. The internal tissue formed by the phellogen is known as *phelloderm;* it augments the cortex, and typically consists of living parenchymatous cells to some extent capable of further division. Indeed, an inward succession of phellogens may arise in the phelloderm and in even more deeply seated living layers. In certain cases the epidermis becomes the phellogen. To the great activity of the phellogen, and to the power of formation of a series of phellogens in deep layers, the value of the cork oak as a source of cork is due.

Cambium in Roots.—The cambium in the root, which is generally found in those plants which have a cambium in the stem, always arises in the conjunctive tissue internal to the primary phloem, and forms new (secondary) phloem in contact with the primary and secondary xylem internally. In roots which thicken but slightly, and whose cambium usually appears late, it is confined to these regions. If the development of secondary tissues is to proceed further, arcs of cambium are formed in the pericycle external to the primary xylem, and the two sets of cambial arcs join, forming a continuous, wavy line in transverse section, with bays opposite the primary phloems and promontories opposite the primary xylems. Owing to the resistance offered by the first formed secondary xylem, the bays are pushed outwards as growth proceeds, and the wavy line becomes a circle. Opposite the primary xylems the cambium either (*a*) forms parenchyma on both sides, making a broad, secondary (principal) ray, which interrupts the vascular ring and is divided at its inner extremity by the islets of primary xylem, or (*b*) forms secondary xylem and phloem, completing the vascular ring. In either case narrow secondary rays are formed at intervals, just as in the stem. Thus the structure of an old thickened root approximates to that of an old thickened stem, and so far as the vascular tissues are concerned, can often be distinguished from the latter only by the position and orientation of the primary xylem.

Growing Points.—The tissues above considered all owe their origin ultimately to the growing points or *apical meristems* defined in the embryonic plant-body. To the great variety of apical meristems found in vascular plants reference alone can here be made. It must suffice to note that in most Pteridophytes there is a single large apical cell at the end of each stem- and root-axis, that it usually has the form of a tetrahedron, that its base occupies the surface of the growing point, and that its apex points inwards. By definite and regular divisions of such a cell a mass of still undifferentiated cells is produced immediately behind the growing point, which is continuously occupied by a residual apical cell. From these undifferentiated cells the tissues above considered sooner or later arise by further growth, divisions and differentiation. In most Phanerogams the *apical* (*or primary*) *meristems,* instead of consisting of single apical cells or of a definite group of initials, are stratified, *i.e.,* there is more than one layer of initials. Throughout the Angiosperms the epidermis of the shoot originates from separate initials which never divide tangentially, so that the young shoot is covered by a single layer of dividing cells, the *dermatogen.* Below this are the initials of the cortex and the central cylinder. Whether these are always in layers which remain separate is not known, but it is certain that in many cases such layers cannot be distinguished. This, however, may be due to irregularities of division and displacement of the cells by irregular tensions, destroying the obviously layered arrangement. In some cases there is a perfectly definite line of separation between the young cylinder (*plerome*) and young cortex (*periblem*), the latter having one or more layers of initials at the actual apex. The separation of layers in the apical meristem of the root is usually much more obvious than in the stem. The outermost layer is the *calyptrogen,* which gives rise to the root-cap, and in Dicotyledons to the piliferous layer as well. The periblem, one cell thick at the apex, produces the cortex, to which the piliferous layer belongs in the Monocotyledons; and the plerome, which is nearly always sharply separated from the periblem, gives rise to the vascular system.

There is generally some definite progression in the actual differentiation of the individual tissues, so that, for example, comparatively simple xylem and phloem elements may be recognized in certain portions of a stem or root before the differentiation of xylem and phloem is accomplished in the stele as a whole. Such first formed xylem and phloem elements are known respectively as *protoxylem* and *protophloem,* and serve for the initial conduction of food-materials, while the later formed elements of the primary xylem and phloem are called respectively *metaxylem* and *metaphloem.*

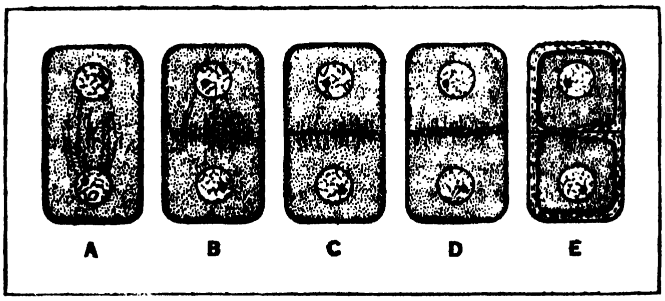
The branches of the stem arise by multiplication of the cells of the epidermis and cortex at a given point, thus forming a protuberance at the end of which an apical meristem is organized. The vascular system is connected in various ways with that of the parent axis by the differentiation of bundles across the cortex of the latter. This is known as *exogenous* branch formation. In the root, on the other hand, the origin of branches is *endogenous.* The cells of the pericycle, usually opposite a protoxylem strand, divide tangentially and give rise to a new growing point, the outward path for which is prepared by digestion of the surrounding tissues. The connections of the stele of such a root with that of the parent axis are made across the pericycle of the latter. The cortex of the new root is never connected with that of the parent, but with its pericycle. *Adventitious roots,* arising from the stem, usually take origin in the pericycle, but sometimes from other parts of the conjunctive tissue.

Thus it will be seen that throughout the vascular plants there are definite and orderly methods of production and distribution of the tissues destined to play their parts in the major or minor processes of life, and that such organisms are well fitted for life on land. (J. McL. T.)

CYTOLOGY

The structure and development of the vegetable cell so far as the protoplasm and the nucleus are concerned are considered in their broader aspects in the article CYTOLOGY.

The recognition of the fundamental similarity of the cells of plants and animals and the identity in structure and functions of animal and vegetable protoplasm which formed the starting point in the study of cytology are conceptions which subsequent investigations have only broadened and confirmed. Nevertheless this agreement, whether it be in the minute structure of the protoplasm or in the details of nuclear mitosis, is accompanied by peculiarities in the cell structure of plants which have had a profound influence in the evolution of the vegetable body. Of these the most important, because far-reaching in their effects, are the presence of plastids in the protoplasm and the existence of the cell wall. In the higher plants the egg is necessarily a naked cell, but when fertilization is accomplished the new cell secretes around itself a membrane—a cell wall—before it begins to grow and divide, and the myriad cells to which it gives rise in the course of its further development are from the first enclosed in a similar membrane.



FROM A. J. EAMES & L. H. MACDANIELS, "INTRODUCTION TO PLANT ANATOMY" (MCGRAW, HILL & CO.)

FIG. 1.—DEVELOPMENT OF THE CELL WALL IN A VASCULAR PLANT
A. Telophase of mitosis in meristematic cell, B. Appearance of swellings on the achromatic fibrils, C. Fusion of swellings to form an equatorial cell plate; fibrils disappearing, D. deposition of new primary wall (middle lamella) between the halves of the split cell plate, E. deposition of a secondary wall layer between the plasma membrane and middle lamella, except in region of a large pit. Primary wall, solid black; cytoplasm stippled, plasma membrane densely stippled; secondary wall shaded

The continuous development which is such a characteristic feature of the structure of the higher plants depends on the presence of persistent embryonic regions or growing points at such places *e.g.*, as the tips of stems and roots. This enables us to study in these regions the formation of new cells, and to trace their development and modification to form the adult tissues of the member to which they belong.

The individual cells appear rectangular in form and consist of a mass of protoplasm containing a large nucleus and separated from the neighbouring cells by a delicate membrane. It is unnecessary to refer to the detailed structure of the protoplasm and the nucleus, since these have already been fully described (*see* CYTOLOGY), but with suitable treatment it is possible to distinguish in the protoplasm of these meristem cells the rudiments of definite protoplasmic organs, the plastids. The nature, purpose and function of these important bodies will be considered below: for the present it is sufficient to say that they are differentiated portions of the protoplasm which perform definite functions.

From such embryonic cells all the tissues of the plant body are formed by processes of growth and differentiation. Growth involves an increase in size of the individual cells which may in some cases result in an enlargement to many thousand times their original volume. This enlargement does not however necessitate a proportional increase in all the parts of the cell. Increase in size is mainly the result of active extension of the cell wall. The protoplasm does not increase in volume in the same proportion and hence cavities appear in it which are filled with a watery fluid —the cell sap. As the wall enlarges these spaces or vacuoles increase in size and number and eventually coalesce to form one large central vacuole in the protoplasm which thus becomes restricted to a comparatively thin layer closely applied to the cell wall (fig. 1, E). The nucleus, which undergoes little change during this process or may even be reduced in size, is at all times embedded in the protoplasm and thus comes to lie close to the cell wall or in some cases it may be slung by delicate protoplasmic strands in a more or less central position in the cell. It is often possible to observe a circulation of the material in these strands, definite streams moving from the cell wall towards the nucleus and vice versa. It is, however, uncertain as to whether this is a general phenomenon.

The Cell Sap.—The cell sap which fills the vacuoles is water in which are dissolved substances of various kinds, some of which are food materials others products of the metabolism of the protoplasm. Its composition is constantly changing but among the substances of constant occurrence are inorganic salts, carbohydrates such as the sugars and soluble nitrogenous compounds; in addition the sap of fully developed cells may contain colouring matters such as the anthocyanins, which are red, violet, or blue and give their characteristic colour to the petals of many flowers, the leaves of such trees as the copper beech and the tissue of the beetroot. The large proportion of the total volume of the cell occupied by the cell sap explains the large percentage of water present in soft vegetable tissues; *e.g.*, cabbage and spinach leaves, roots of turnip and beet and shoots of asparagus contain over 90% of water.

The cell wall and the protoplasm are both freely permeable to water and indeed the former is also permeable to the molecules of crystalloid substances. The living protoplasm, however, may be described as semi-permeable since it may restrict the passage of dissolved substances either into or out of the vacuole. One result of this property of the protoplasm is that, whereas at a given moment the pressure of molecules of water inside and outside the cell may be equal, there may exist in the vacuole in addition a pressure due to the molecules of the salts; the cell is in consequence distended, the wall is stretched and owing to its elasticity exerts a counter-vailing pressure. Such a cell is described as turgid and in this condition it acquires a certain rigidity analogous to that of a distended air bladder.

This characteristic of the vegetable cell has played an important part in the evolution of the plant body since it has rendered possible the development of plant organs of relatively large size with a minimum organization of skeletal tissue. Such structures as the leaves of herbaceous plants—though provided with a network of veins—maintain their form and position only by the turgidity of the living cells of which they are largely built up. Loss of water from the individual cells results in a shrinkage of the tissues as a whole, and the familiar appearance of wilting or flagging of plants deprived of water is brought about in this way.

Plastids.—The plastids or chromatophores are portions of the protoplasm which have become specialized for the performance of certain functions. They are readily distinguished in the adult cell by their size and definite form and they are often conspicuously coloured. Leucoplasts are colourless and occur in the cells of the deeper lying tissues where light cannot penetrate—if exposed to light they often become green. They are frequently concerned with the formation of starch grains. Chromoplasts are colour-carrying bodies giving red and yellow colours to the petals of flowers, ripe fruits, etc.; they contain yellow and red pigments such as xanthophyll and carotin. The most important of all the plastids, however, are the green chloroplasts, chlorophyll bodies or chlorophyll corpuscles as they are variously termed. They contain chlorophyll and are of universal occurrence throughout the vegetable kingdom with the sole exception of the important group of the Fungi. It is by means of this pigment that the plastids are enabled in the presence of light to form carbohydrates from water and carbon dioxide.

The importance of this process cannot be overestimated, since it is the starting point in the manufacture of the food of all living organisms and its activity has made possible the existence of plants and animals upon the earth. (*See* PHYSIOLOGY.) Chlorophyll when extracted from plants by suitable solvents can be shown to contain a number of pigments. The green, blue-green, yellow and red have been already mentioned. In form the chloroplasts are extremely variable and the Algae (*q.v.*) show a rich variety of shape; in the higher plants however they are discoid in form. Like the leucoplasts they frequently show inclusions of starch grains. They may increase in number by dividing into two halves by simple constriction. They have been shown to be present in the egg cell of some plants and are, in these cases, thus passed on from one generation to another, but they have not been demonstrated in the sexual cells of all plants.

The Cell Wall.—The cell wall in meristematic cells is an extremely delicate membrane but, with the completion of the growth in size of the cell, it is increased in thickness and may in certain cases undergo considerable modification. It is commonly regarded as a secretion of the protoplasm and it is in living cells in intimate relation with the protoplasm which may interpenetrate the particles of its substance. This close relation can be readily appreciated when the process by which the wall is first laid down is considered. From the beginning of the plant's existence as a single cell, all new cell formation consists in the division of a pre-existing cell into two halves by the formation of a dividing wall. In this process the cytoplasmic spindle which functioned in the preceding nuclear division (*see* CYTOLOGY) plays an important part. The spindle fibres—increased in number—show swellings or thickenings in the middle of their length (fig. 1, B), which coalesce and form a continuous "cell plate" which is extended until it reaches the side walls of the mother cell. This cell plate is not however the cell wall; it is of protoplasmic nature and splits into two layers between which the true wall substance is laid down (fig. 1, D). The subsequent growth of the cell wall is facilitated by its intimate penetration by the protoplasm, which lays down fresh materials between the existing particles (intussusception), and later adds to its thickness by the deposit of fresh layers of material on the inner surface of the primary wall (apposition).

The primary wall, laid down in the manner above described, might be regarded as common to the two cells concerned in its formation, but many facts go to show that it is either a double membrane from its inception or that it readily splits into two. The result is that every cell is surrounded by its own individual wall. This is seen very clearly in the development of elongated cells such as fibres, which may grow to many hundred times their original length. In this process they may change their position, sliding over the surface of neighbouring cells and making contact with cells of different, and of more remote, origin. Such elongated cells as the fibres undergo considerable thickening of their walls when their growth is completed. This thickening is originally of cellulose, but it may undergo secondary changes becoming wholly or in part lignified, thus rendering the wall firm and hard and better adapted to serve the purpose of mechanical support. Thickening and lignification of the wall is also characteristic of the cells concerned in the formation of the water-conducting elements. With the completion of these changes in the cells of the strengthening and water conducting tissues the protoplasm disappears and the walls alone remain.

Plasmodesma.—The living cell in a complex multicellular plant body is a unit, but not an independent one, and its functions must be conditioned by, and related to, the activities of the organism as a whole. This must involve a close connection between the living protoplasm of neighbouring cells and this is effected by delicate connecting strands, the plasmodesma, which traverse the walls. These represent in some cases the persistence of the original continuity of the protoplasm of two sister cells, but for the most part they are probably new contacts established when growth is completed. The presence of these delicate connections has been established in a large number of cases, and it is probable that they are of universal occurrence in the higher plants. They play a part in the correlation of the functions of the cells, and they may also provide the means by which stimuli can be conveyed through long tracts of tissue in those cases, where the region stimulated is distant from that in which the response is shown.

(R. J. T.)

DISTRIBUTION AND ECOLOGY

The distribution of plants can be considered from two main aspects. The present or past distribution of species, genera and families, termed *floristic plant geography*, can be studied both for its own sake and as a factor in determining the location of human activities or features of the earth's surface. But besides this purely geographical aspect the facts of distribution can be considered in relation to their causes; the influences of climate, of topography, of the soil conditions, of other plants, of animals, and even of the past history of the superficial crust of the earth and of the species itself. It is this relation of plants to their environment, in its widest sense, and the mutual effect of environment and organism, which is the province of *ecological plant geography*, or briefly plant ecology.

Floristic Distribution.—The floristic distribution of species exhibits the greatest possible variation from the species which as a wild plant is confined to a limited area (*endemic*) to wide-ranging species such as many microscopic plants (*e.g.*, some bacteria) which are apparently universal in their occurrence. There are probably no vascular plants that are strictly cosmopolitan, but the common bracken (*Pteridium aquilinum*) and the reed (*Phragmites communis*), though far less common in the tropical regions, are feral species in the most diverse climes (the former, however, notably absent from oceanic islands). In striking contrast are such plants as the fern *Thyrsopteris elegans*,—an endemic confined to the Island of Juan Fernandez or *Pringlea antiscorbutica* restricted to the tempestuous shores of Kerguelen.

Endemics are an especial feature of oceanic islands as is shown by the flora of Madagascar, which comprises some 4,000 species of vascular plants and contains no less than 75% of endemics. In New Zealand the proportion of endemics is 74%, whilst in Hawaii the endemics constitute 80% of the entire flora. By contrast the floras of continental islands are practically destitute of endemics, as is shown by that of Britain, which amongst its flowering plants probably includes but one endemic of specific rank, namely, the wolf's-bane (*Aconitum anglicum*).

It is clear that when a new species originates it will not immediately attain its climatic limits but its spread will be a gradual process, occupying a longer or a shorter time according to the efficiency of the means whereby the dispersal of its seeds or other reproductive bodies is attained. It is the belief that this process is in general secular rather than rapid, which has led to the view that the area occupied by a species, genus, or family is roughly dependent upon its age. Willis has adduced evidence to show that the majority of endemics are species of recent origin which have either not had sufficient time to spread over a larger area (*e.g.*, local endemics in continental areas) or have been prevented, by the presence of natural barriers, extending beyond their place of origin. The latter explains the high proportion of endemics on oceanic islands. On the other hand, it is certain that some endemic species are relics of a former more extensive area of occupation the remnants of a bygone vegetation. The fern genus *Matonia* is at the present day represented by three species, of which two are confined to Borneo and the third also occurs in the Malay Peninsula; yet fossil evidence indicates that ferns of this affinity had an almost cosmopolitan distribution in Mesozoic times. The *Gleicheniaceae*, the *Schizeaceae*, and *Marattiaceae*, families of ferns now practically absent from the northern hemisphere, furnish further examples of area diminishing with the lapse of time. Amongst the flowering plants the present restricted distribution of *Ginkgo biloba*, the tulip tree (*Liriodendron tulipifera*) and the sequoias, affords a marked contrast to the widespread occurrence of species of these genera in Tertiary times and shows the importance of the past history of a group in appreciating the significance of the existing representatives.

Frequently the members of a genus comprise one or more species which extend over a large area, whilst the remainder are of much more restricted distribution and occupy areas either included in or overlapping the range of their more widespread congeners. Illustrations are furnished by the she-oaks of Australia (*Casuarina*), with the littoral *C. equisetifolia* extending from east Africa and Madagascar to the Society islands and Burma and the Philippines to Tasmania, within which area occur a number of other species. Again the genus *Mercurialis* includes the dog's mercury (*M. perennis*) and *M. annua*, which are of wide range, whilst the five or six other species extend over comparatively small areas in the Mediterranean region and eastern Asia. It is probable that in such genera the species of more local occurrence are derivatives of the wide-ranging types, but it is also evident that were the widely dispersed parent types to die out the other species of restricted distribution would come to present the condition of discontinuous distribution which is a feature of many genera and families at the present day. The pipeworts (*Eriocaulon*) are chiefly found in tropical and sub-tropical regions, but *E. septangulare* is found in the eastern United States, the west of Scotland, and the west of Ireland. Of over 400 species of heath belonging to the genus *Erica*, the majority are concentrated in Cape Colony and the Mediterranean area. The *Proteaceae* and *Cycadaceae*, containing many very localized genera, now exhibit a discontinuous distribution in tropical and sub-tropical regions, but there is little doubt that the *Cycadaceae* extended over a large part of the world in Jurassic times and the *Proteaceae* were probably much more widely distributed in the Tertiary epoch than at the present day. Discontinuous distribution in the species may be the outcome of irregularities of dispersal, the result of extinction from parts of its former range, or even due to origin of the species in more than one locality.

Effects of Glaciation.—It is quite impossible to appreciate the present distribution of species in either North America or northern Europe without recognition of the profound changes consequent upon the last glacial epoch. During Cretaceous times there would appear to have been a remarkable uniformity in the character of the vegetation of the world, with warm temperate types as far north as Greenland. This uniformity was succeeded by a differentiation in the Tertiary period. On either side of the tropical belt there probably existed a zone of forest presenting a mixture of temperate and subtropical types, southern types being present in the northern hemisphere and northern types, such as the true beeches and the common oak (*Quercus Robur*), being present in the southern hemisphere. Mrs. Clement Reid has admirably demonstrated, by a comparison of successive floras of the Pliocene period of Europe, the gradual disappearance of exotic types as the Pleistocene approached, probably accompanying a diminution of temperature. It is due to the work of Heer on the arctic fossil flora, the writings of Asa Gray, Saporta and Hooker that the fossil floras of the past have been so ably utilized in the elucidation of the peculiarities of the distribution of the present. The holarctic distribution of a large assemblage of species prior to the glacial refrigeration is the clue to the resemblances between the American and east Asiatic floras. Of these migrants, driven southwards by the increasing cold, relics remain in the genus *Sequoia,* now only represented by two north-west-American species, in *Ginkgo biloba,* confined to western China, in the American genus *Liriodendron* and the Chinese *Glyptostrobus.* The magnolias no longer occur wild in Europe as they did in the past, but still survive both in Asia and America. Of the genera cited Depape has recorded Pliocene remains from the valley of the Rhone of *Sequoia sempervirens, Liriodendron tulipifera, Ginkgo biloba,* and *Glyptostrobus heterophyllus.* The elimination of these and many others from the European flora is probably to be attributed mainly to the presence of natural barriers against the southward retreat, such as the Mediterranean, whereas in Asia and America there was a continuous land bridge to a climatic sanctuary, the temporary home of some, the permanent retreat of others.

During the Ice age itself the flora consisted of definitely arctic types and a considerable number of other hardy species which survived the cold in the areas, probably of considerable extent, which were not actually covered by ice. Judged by the frequency of the remains in sub-fossil deposits of the glacial period in Europe the commonest species were the mountain dryas (*Dryas octopetala*), the dwarf birch (*Betula nana*) and various willows of mat-like habit, such as *Salix reticulata, S. polaris,* etc. It is noteworthy that the species cited and a number of others prevalent at that period are now most characteristic of arctic regions but also occur in warmer climates on what may be termed arctic islands, namely, the summits of the higher mountains, a discontinuous distribution that can be attributed to survival from glacial times. With the final retreat of the ice, which in northern Europe probably took place somewhere about 14,000 years ago, the recolonization of the glaciated areas by the less hardy species began.

The colonization thus begun has continued ever since. The fact that Ireland possesses but two-thirds of the vascular plants of Britain whilst the flora of England, though richer than that of Scotland, is less varied than that of the neighbouring areas of France emphasizes the importance of the facilities for dispersal of fruits and seeds in determining the distribution of species. The rapid spread of the Canadian pondweed (*Elodea canadensis*) from Market Harborough, where it first appeared in England in 1847, of *Veronica persica,* or more recently of the rayless mayweed (*Matricaria suaveolens*), a native of Oregon, all of which have become abundant over a great part of Britain; or, again, the spread of the prickly pear (*Opuntia inermis*) at the rate of a million acres a year in Australia and the choking of the waterways of Florida by the water hyacinth (*Eichornia crassipes*) all bear witness that area is not necessarily a criterion of age and that the process of colonization is still going on, a process in which the disturbing influence of the hand of man plays no small part.

Ecological Factors.—The most superficial observation shows that species are not uniformly distributed throughout their range and that certain conditions favour one kind of plant rather than another. In the ecological concept the idea of competition is never absent and the effect of the external conditions upon the constituents of the vegetation of any region is largely dependent upon their selective action. The sum total of the external circumstances surrounding the plant is termed the *habitat* and the various conditions that together determine distribution are termed the habitat *factors,* of which some are physical and others biological.

Climatic Factors.—Of the physical factors the most important are climatic and of these temperature would appear to play the major rôle. Hence we find that the main vegetation zones on the earth's surface have a latitudinal distribution and that the species which has an extensive north and south range has commonly a wide range in the east and west direction also. Whilst some species, as already noted, are almost cosmopolitan, it is true of the majority that they do not occur both in tropical and arctic regions. In some cases it has been shown that the species comprises several geographical races with different capacities for endurance of climatic extremes, but there is little evidence to show that species can become adapted to climatic extremes that they could not initially endure. Many garden plants are cultivated in the open beyond the limits of their natural range, showing that the climatic conditions need not be lethal in order to delimit the area of a species.

By diminishing the rate of growth or inhibiting reproduction temperature may effectually prevent the maintenance of a species in competition with other plants although there is a considerable margin before the lethal limit is reached. Extremes of temperature, however, cause death in many plants by coagulation of the living cell contents, and in general the susceptibility to such extremes is directly proportional to the amount of water which the plant or part of the plant contains. Hence seeds which have a very low content of water are exceptionally resistent whilst succulent shoots are especially susceptible. Rapid changes of temperature are far more liable to prove fatal than changes of the same amplitude which occur slowly.

In tropical and sub-tropical regions where there is no dry season the vegetation consists of broad-leaved evergreen forests, but where, as in temperate latitudes, a warm and cold season alternate, the characteristic type is deciduous woodland; whilst in still higher latitudes, where the growing season, or frostless period, is of short duration, the prevailing types of forest consist of narrow-leaved evergreen conifers. A similar zonation to that presented from the Equator to the Poles is seen in the altitudinal zonation on the higher mountain masses. Such is well illustrated in Corsica where the olive characterizes the belt from sea-level to 400 metres, the chestnut from 400m. to 1,000m., pines (*P. Pinaster* and *P. Laricio*) and beech from 1,000m. to 1,600m.; the alder (*Alnus suaveolens*) the sub-alpine zone from 1,600m. to 1,900m. and scrub of the dwarf juniper (*Juniperus nanus*) with *Berberis aetnensis* up to 2,000 metres.

The importance of temperature and the length of the growing season is further shown by the altitudinal distribution of individual species, which varies markedly in correspondence with the latitude. For example, *Polygonum viviparum* attains to 1,230m. in Scotland at 56·48 N. Lat., on the Swiss alps it is found at over 2,850m. (9,000ft.), and on Mt. Everest (27·59 N. Lat.) reaches an elevation of 4,460m. (14,500ft.). Study of comparative altitudes in different latitudes shows that the upper limits tend to rise on the higher mountains and in areas of large mountain masses, which indicates the importance of exposure conditions.

The extreme conditions tolerated by living vegetable organisms is shown by the fact that spores of bacteria can endure immersion in liquid air whilst certain blue-green algae (*Phormidium laminosum, Mastigocladus laminosus*) occur in water at temperatures above 49°C. Even amongst the flowering plants the resistance of some species to cold is considerable, *Larix siberica* for instance growing where temperatures of −70°C are not unknown, whilst seeds are particularly resistant to both heat and cold. Here, too, attention may be called to the extreme altitudes attained by some flowering plants, *Arenaria muscosa* being found at 20,400ft. on Mt. Everest, the highest recorded station for a member of this class.

Precipitation.—Of almost equal importance to temperature is the amount and seasonal distribution of precipitation either in the form of rain or snow or as dew and fog. In regions of equivalent temperature forests will in general occupy the areas of highest precipitation, deserts the areas of lowest precipitation, and grasslands the areas of intermediate humidity. In the United States, for instance, the mean annual rainfall in the desert region ranges from 0–30in., in the prairies from 20–30in., and in the regions of forest from 30–90in. In any estimate of the influence of rainfall, however, the humidity of the air is necessarily a considerable factor and the efficacy of a given precipitation will be largely influenced by the temperature changes, upon which the rate of water-loss from the surface of the plant and from the soil in which it grows so largely depends. Further, this water-loss will be greatly augmented by wind, and so the velocity and frequency of air movements have an important influence on the limits of species and plant-communities. The frequent incidence of high winds inhibits the growth of trees near the summits of mountains, both by their drying action and mechanical effect, whilst the strong winds and low temperature together determine the distribution of arctic Tundra.

Illumination.—Since all green plants manufacture their organic food by means of the radiant energy absorbed from sunlight, the intensity and duration of this illumination naturally affects the distribution of species. Many woodland plants are so constituted as to function best in this respect when growing in comparatively weak illumination, whilst others, such as many littoral species, attain their optimum rate of food production in full sunlight. Even the weak light which reaches the floor of a woodland is sufficient for the requirements of some mosses, but when the shade is too intense the vegetation is confined to parasites and saprophytes and so the rich fungus flora of a dense beechwood or pinewood becomes one of its salient characteristics. It has, moreover, been found that the length of the period of daily illumination may be an important factor in influencing reproduction. Some species appear to be indifferent to the length of the period of daylight, except in so far as the amount of organic food they manufacture is dependent on the total radiant energy they receive. Other species respond to a shorter daily illumination by earlier flowering and fruiting, whilst with still other species the effect is a retardation in the reproductive process.

Nevertheless, though the individual climatic factors play each their separate part, it is mainly upon their interaction that distribution of species depends. Thus it is that some are particularly associated with oceanic climates characterized by small amplitude of temperature and high humidity, whilst others are found in the drier and more extreme conditions of continental areas. Examples of the former are furnished by the petty whin (*Genista anglica*) and the wild hyacinth (*Scilla nutans*), features of the west of Europe, whilst the latter are represented by various species of *Eryngium* and *Artemisia* of the Russian steppes.

The Soil.—The character of the soil is chiefly important as to its physical structure, except where the chemical constitution exhibits extreme conditions. For upon the size of the constituent mineral particles and the proportion of organic material which the soil contains depends in large part its capacity to retain the water which reaches it in the form of precipitation or by capillarity. It is the feeble power of such retention that renders the conditions on a sand dune or a shingle beach comparable to those of a desert even in regions of high precipitation and humidity. It is in great measure differences in *water capacity*, as this power of water retention is termed, that are responsible for the different types of vegetation on clay, sand, and peat, within an area of uniform climatic conditions. Nevertheless, other soil factors, such as the chemical nature, the reaction, the nature of the soil atmosphere and the constitution of the teeming population of micro-organisms, etc., all play a part in determining the relative suitability of soils for one species or another. The soil conditions in untouched vegetation, however, present a very different distribution from the comparative uniformity of agricultural land, a definitely stratified organization, as a consequence of which species growing intermingled but with root systems of differing depths of penetration may be occupying very different types of soil both as regards chemical and physical constitution. The direct influence of the chemical nature of the soil is often difficult to separate from its indirect influence on water supply, absorption of soluble salts, etc. This is well seen in the vegetation of calcareous and non-calcareous soils. The so-called calcicole species which frequent the former may prefer calcareous soils either because of their physical qualities, because of their neutral or slightly alkaline reaction, or because of their chemical properties. Further, such association may be obligatory or merely preferential. Preference for a particular soil type is sometimes a feature of an entire genus, as that of *Clematis* for calcareous soils, whilst in other groups closely allied species may have very different requirements.

Biological Factors.—These comprise the effects of plant on plant and the relation between animals and plants. Of these biological factors, however, the most important is the influence of man. It is largely due to man that the present tree limit in the alps is considerably below its former altitude, whilst even in comparatively unsophisticated regions of the tropics considerable changes have resulted from the practice of migratory cultivation and the artificial extension of grassland at the expense of forest, both for domestic animals and the encouragement of wild game. The profound effect of rabbits on natural vegetation has been well exemplified in New Zealand and Australia, whilst the attacks of field mice, mollusca and various parasitic fungi, *inter alia*, considerably affect the efficiency of reproduction in many wild species. On the other hand, the beneficial effects of earthworms, moles, ants, etc., is analogous in nature to the action of the plough in maintaining adequate aeration of the soil. Many flowers depend upon insects for their pollination, and hence the area of a species may be restricted by that of its pollinating agent.

In addition to the effects of climatic, edaphic (soil), and biotic factors, there are the historical factors to which allusion has already been made, and in this connection it must be recognized that the vegetation of yesterday has in large part been responsible for the conditions which determine the vegetation of to-day. The habitat is not static, but dynamic, and the present is but the link which joins the conditions of the past to those of the future.

Autecology.—The success or failure of the individuals of the species in one area will depend not merely on its ability to flourish in the environment there present but also on its capacity to modify that environment and itself to become modified. The study of this relation of the individual to its surroundings is termed *autecology*. A few examples will serve to illustrate the importance of the life history and structure of the organism in determining its fitness for a particular station or habitat. Thus annuals are an especial feature of deserts, where the short relatively wet season is occupied in rapid growth and reproduction whilst the dry hot season is passed in the seed state. The same quality has enabled many plants to become weeds of arable land and others to survive the rigours of a cold season. By contrast the vegetation of arctic regions is characteristically rich in perennials, for the growing season is so short and the temperature so low that growth is a slow process, and the annual species which occupies a considerable period in attaining the reproductive state is at a disadvantage in competition with perennial types in which the flower rudiments are often formed already in one season preparatory to their expansion in the next. Many of the herbaceous plants of woodlands exhibit exceptionally early leaf expansion, and hence their leaves are receiving light and manufacturing food material for weeks, and sometimes months, before the canopy of foliage of the shrubs and trees is formed above. This quality of precocious leaf development has enabled its possessors to occupy woodlands in which the light intensity during the summer months may be less than 1% of that in the open.

The possession of a relatively small leaf surface, a tufted habit, low growth, or hairy leaves are a few amongst many external features which tend to reduce the rate of water loss from the leaf surface (transpiration) and thus enable their possessors to occupy drier areas than would be possible for them in their absence. Such features are often accompanied by a microscopical internal structure also tending to check the rate of water loss, and plants having an aggregate of such feature are often termed *xerophytes*, from their capacity to grow in arid situations. Many plants, on the other hand, are entirely devoid of such transpiration checks and even exhibit features which tend to promote water loss, and often possess means of secreting liquid water. Such plants are quite unsuited to dry situations, but are admirably adapted for the humid situations in which they flourish.

Some species owe their success to a remarkable capacity for vegetative spread, as, for example, *Mercurialis perennis* and *Epilobium angustifolium*, others to a copious seed output, as, for instance, the foxglove (*Digitalis purpurea*), of which one plant may produce a million seeds in a single season. Contrast this with the seed output of another woodland species, *Allium ursinum*, which often does not exceed 40 seeds per annum. The rosebay willowherb (*E. angustifolium*) will often spread at the rate of 60cm. a year by means of its rhizomes and at the same time produce some 50,000 seeds, whereas its congener, *E. montanum,* only produces from 4,000 to 13,000 seeds in a season and spreads vegetatively about 1·1cm. per annum. The equipment of species in the struggle for existence is thus very unequal.

Seed Dispersal.—Many seeds and fruits are dependent on wind action for their distribution, and some, such as the parachute-like fruits of the goatsbeard (*Tragopogon*), the plumed seeds of the willows and willowherbs, or the winged seeds of the tropical *Bignoniaceae,* are wonderfully fitted for this mode of dispersal. Others, such as the burr-fruits of the goose-grass (*Galium aparine*), enchanter's nightshade (*Circaea*) and herb bennett (*Geum urbanum*), become attached to the coats of animals by means of their hooked appendages, whilst the seeds of many berries are swallowed by animals and deposited in their droppings, often at great distances from their source. Here, however, it should be noted that the crops of birds on migration are usually empty and their plumage remarkably clean, so that bird carriage is not so important an agent as might be supposed. Still other seeds or fruits, like those of many waterside plants, have a buoyant structure and are carried to new habitats by means of streams and ocean currents. The efficacy of this means of dispersal is shown by the carriage of seeds of *Entada scandens* from South America by ocean currents, which frequently deposit them along the west European seaboard in a viable condition.

The Social Life of Plants (Synecology).—The foregoing considerations lead naturally to the conception of definite communities of plants, and it is the study of these social groupings which is the particular domain of *synecology.* The largest groupings that can be recognized are related to the broad climatic features of the earth's surface; such are termed *formations* and are well represented by the tropical *rain forest,* a community characteristic of areas within the tropics with high and continuous rainfall, consisting of a luxurious vegetation in which there are a great variety of broad-leaved evergreen trees, numerous woody climbers (*lianes*), and epiphytic plants, the whole presenting a great complexity of structure. Other examples of formations are the deciduous forests of temperate regions, the grassland formations of the American prairies and the African veld, or the deserts of arctic and tropical regions. These formations can be further subdivided, according to the species which play the major rôle in the plant community, into *associations,* where several species take a leading rôle, or *consociations,* where there is one predominant species. Since even in these the subordinate species vary from one part to another, *societies* within the association can be recognized.

The deciduous forest formation of America presents in Indiana and Missouri associations in which oak and hickory are the chief features, whilst in the region of the great lakes it is represented by an association of birch and maple. In central Europe the same formation is represented by the very mixed forests of beech, hornbeam oak, etc., of the Danube region, by the Mediterranean chestnut forests, by the oak forests of Austria and other types. In Britain consociations are the rule, each characterized by a single dominant tree and associated with particular soil conditions. Thus the ashwoods are chiefly found on limestone soils, where the conditions are moist; beechwoods on dry soils, particularly those derived from chalk; birchwoods constitute the uppermost zone of woodland in mountain districts and also occur as a temporary phase on felled areas; alderwoods occupy the wettest soils; oakwoods of *Quercus Robur* are a feature of the moister and more fertile clays and loams, and oakwoods of *Q. sessiliflora* of the less fertile, acid, and usually drier non-calcareous soils, especially on the valley slopes of the west. Within an English oakwood some areas are covered with a carpet of *Mercurialis perennis* and *Scilla nutans,* others with *Anemone nemorosa* or *Ficaria verna,* furnishing examples of societies within the consociation. Such illustrations serve to indicate the use of these synecological terms; but for an account of the plant communities of the world the reader is referred to the works cited on p. 18.

Every plant community has something of the attributes of an organic unit, in that it possesses a more or less definite structure and has a life history in which juvenile, adult, and senile phases can be recognized. The structural organization is well illustrated in the temperate deciduous woodland, where three definite strata are usually present, respectively consisting of trees, shrubs and herbs, whilst beneath the lowest tier or ground flora there is often a carpet of mosses and the surface soil is rich in fungi and bacteria. Although less conspicuous, these flowerless plants are just as important a part of the community and have as definite a floristic composition. Beneath the surface the root systems of the higher plants exhibit a stratification comparable to that of the aerial organs, and the differing depths to which the roots of different species penetrate, as also the different periods at which they make their maximum demands on the food supply in the soil solution, are features which tend to reduce the competition between species and render possible that dense intermingling which results in the succession of seasonal changes. It must, however, be realized that the architecture of any community necessarily connotes different conditions in its various parts so that the environment occupied for example by the ground flora of a tropical or temperate forest, or by the lowest stratum of a fen is markedly different, as to humidity and illumination, from that of the tree layer in the one or the tall reeds in the other.

The different associations in a plant formation show an analogous structure often built up by very diverse species, and no better example of this could be furnished than by the desert vegetation of Texas and Mexico, characterized by succulent Cactaceae, and that of Africa, characterized by succulent Euphorbiaceae. Some of the members of these totally unrelated groups are so similar when not in flower as to be most readily distinguished by wounding, since the euphorbias possess milky juice which the cacti do not. Each association is distinguished by the presence and relative abundance of certain species and the absence of others. Those which are almost invariably present in a community are termed *constants,* but their diagnostic value is often low owing to their constancy in more than one association. Examples are furnished by *Mercurialis perennis* in the beechwoods of Britain and *Viola sylvestris* in the oakwoods. Of greater significance are the *characteristic* species which occur more or less exclusively in a particular community, as *Hordeum sylvaticum* and *Monotropa hypopitys* in the beechwoods of Britain or *Psamma arenaria* on European sand-dunes. Such characteristic species may be at the same time constants but are often of local occurrence. Many of the subordinate or accessory species are found in a variety of communities but have their characteristic frequency in each.

Succession.—Careful observation shows that, quite apart from the periodic rhythm of the seasonal changes, no community is stable. The physical environment itself is slowly altering, partly as a consequence of climatic action, partly through the influence of the living covering. Commonly, these changes are too secular in character to be readily appreciated, and it is only where the alterations in the physical environment are unusually rapid that the existence of a definite life-history in the plant community can be easily observed. In general, the tendency is for communities characterized by extreme conditions, as of dryness or wetness, to approach the mean. The process is well illustrated by the formation of sand-dunes, where the early stages consist of sandy accumulations around plants of marram grass (*Psamma*) or other pioneer species; these by their continued growth, as fresh layers of sand are added, not only stabilize the sand but by the decay of their older parts add organic material and so materially increase the water-retaining capacity of the soil. With the consequent amelioration of the extreme desert conditions species less specialized than the first colonizers can become established, and so there is a cumulative increase in the stability and quality of the habitat. The original dune-units increase in size and coalesce, so that the "yellow dune" gives place to the "grey dune," carpeted with continuous vegetation, and ultimately comes to bear scrub or even forest. Similarly the first occupation of the submerged mud in some estuary by almost microscopic seaweeds is the vanguard of a sequence of plants which progressively raise the level of a salt-marsh till it becomes pasture often of high economic value The zones of vegetation which can be seen bordering the margin of a shallow lake present a sequence in space from within outwards which corresponds closely with the sequence of changes in time which led to the present condition of the outermost. Another familiar example is the passage of enclosed pasture to scrub and finally woodland. In such *successions,* as these sequences are termed, each phase is distinguished by the presence of certain species, and the number and size of these tends usually to increase as the succession proceeds. Frequently in the final stages, however, one or two species again come to predominate, and since these often determine the physiognomy of the community they are frequently referred to as the *dominants.* Successions have been extensively studied by American ecologists and F. E. Clements has utilized this aspect as the basis for a classification of plant communities.

Competition.—Except perhaps in the so-called "open" communities such as those of deserts, where the individual plants are separated by bare soil, there is probably always direct competition between the constituent members. The conditions of the habitat exert a selective action, stimulating the development of certain species and depressing the vigour of others. If protected from competition many species can grow in habitats where they do not occur naturally. Many aquatics can survive under terrestrial conditions, and a large proportion of alpines succeed under cultivation in the lowlands. It is thus commonly not a question of whether or not a species can grow, but whether it can grow well, and competition often resolves itself into a capacity to obtain the requisite share of such essentials as light, air, water and mineral salts. In competition for light the naturally taller species is at an advantage; it can grow above and shade its competitor. Thus, wherever soil and climate can support forest vegetation, this tends to be the end phase or "climax" in the succession. So, too, trees which cast a deep shade are usually successful in competition with those having a light canopy. The birch, which by reason of its light wind-born fruits readily colonizes denuded woodland areas, eventually gives place to trees of heavier canopy such as the oak. Large size, however, is usually associated with delay in reproductive activity and the prolonged life-history renders the arboreal habit less successful than the herbaceous under the stress of conditions imposed by the presence of man. This is reflected in the steady diminution of the area occupied by natural forests.

Almost any feature in the organization or life-history of the individual which fits it for its particular habitat is at the same time a passive agent in its survival; but amongst the features which may be regarded as of importance in aggressive competition may be mentioned especially the rate of vegetative spread, the annual output of seeds, the efficiency of the mechanism of dispersal, and the extent and character of the root and shoot systems.

Economic Aspects.—Finally, mention should be made of the importance of the study of plant communities and their successions for the proper control and exploitation of forests and the maintenance of high yielding pastures. The naturally occurring species of an area serve as a valuable guide to agricultural practice, since their presence is in effect a product of the complex built up of soil and climate. A study of the natural relations of species is, moreover, a useful guide to their artificial juxtaposition in the practice of agriculture, forestry and horticulture (*qq.v.*).

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PHYSIOLOGY OF PLANTS

The physiology of plants deals with the functions of the living plant as morphology and anatomy deal with form and structure. Physiology aims to explain the functions of an organism in terms of physical and chemical processes. Physiology thus considers the living organism solely from the mechanistic standpoint, *i.e.,* from the standpoint that the organism is a machine albeit a very complex one. In this attempt to explain the organism in the terms of a machine the physiologist is supported by the fact that the organism appears to obey so-called physical laws in much the same way as does dead material. The living organism for example obeys the law of the conservation of energy, the amount of energy given out by the organism being equal to the amount taken in in food; again the plant or animal conforms also to the second law of thermodynamics which relates to the use of free energy.

Characteristics of Living Organisms.—Although it is impossible to give an exact definition of a living organism some of its characteristics may be pointed out. Whether one is dealing with a plant or animal of a single cell, or of a large organism such as an elephant or a tall tree, it is evident that it is a machine constructed to carry on certain processes, such as the absorption or building up of food; the process of respiration (*see* below) and the processes of growth and reproduction. One great difference between the living machine and any other machine is that the living machine is infinitely more complex than any man-made machine. Then again the processes going on in the organism are not independent of one another but are to a high degree, what is called, *integrated.* All the processes are interlinked or related, the finished material of one process being often the raw material of the next, and all being so closely associated as to lead to movement or growth or reproduction or some other activity of the organism. Another marked characteristic of the living machine which distinguishes it from all other machines is its power, to put it colloquially, to build itself up as it goes along. In other words the growing organism is a functioning unit which adds to itself and increases the size of the machine by its own functional activity. Another characteristic of the plant or animal is its constant reaction to the environment and its constant adaptation to changes in the environment. It is true that a carefully dried seed kept at a low temperature may appear to be quite inert, though still alive as is shown by its power of germination under suitable conditions; yet all active organisms show a constant interchange with their environment. Even in the case of the seed it is probable that some interchange, such as respiration, is still going on though at such a slow rate that our present methods of analysis are too coarse to recognize it. Another characteristic of the organism is that any apparent steady state or equilibrium is not a *static* but a *dynamic* one. If the normal organism appears to be in an inactive state it is simply that the constructive processes just balance the destructive processes, not that the processes are at a standstill. The living organism is like a battery which is constantly running down and requires constant recharging, though the recharging goes on at the same time as the discharging. The majority of cells require oxygen for their mere continued existence even in a resting condition and additional oxygen when in a state of activity. This need of oxygen even during quiescence indicates that a quiescent state of the cell is only an apparent quiescence, a state of dynamic not static equilibrium. Again the giving out of heat by all living organisms even when apparently inactive indicates the dynamic equilibrium of chemical processes going on in the cells. These exceedingly intricate processes continue unceasingly throughout the life-period of every cell in the simplest as well as in the most complex organisms.

Organization of Cell.—All living cells contain, or consist of, a viscous, glairy material (somewhat akin in consistence to unboiled white of egg) known as protoplasm. Protoplasm is not of course a single substance but a very complex system; it has been described as the "physical basis of life" since life as far as we know, does not appear to exist apart from protoplasm. An analysis of an active plant tissue, like lettuce or beet leaves, shows that it contains about 90% water. Of the *dry* material we should find carbon 38·19%, hydrogen 5·1%, oxygen 30·8%, nitrogen 4·5% and ash 21·5%. Similar results would be found for most plant material in the dry state though resting materials such as the potato tuber and the wheat grain would have only 2–4% of ash. Active protoplasm, and living material generally, is characterised by a high percentage of carbon owing to the large amount of organic matter, and in plants by a high percentage of oxygen owing to the large amount of oxygen-rich materials as carbohydrates (sugars, starch). A small proportion of nitrogen is also always present in living material. In ordinary analyses of plant material the protoplasm is only a small proportion of the material, a large proportion is dead cell-wall material, the contents of the cell vacuole (*see* above, *Cytology*), and protoplasmic inclusions. The nearest approach to an analysis of protoplasm is that which has been made of certain myxomycetes (*see* FUNGI) which exist as naked masses of protoplasm. Kiesel (1925) has examined *Reticularia lycoperdon.* He finds in a hundred parts of the dry weight:—protein, 29·1, other nitrogenous substances, 12·0, nucleic acid, 3·7, oil 19·1, carbohydrates generally 9·9, glycogen 15·2, also lecithin and cholesterol. This analysis is of course very incomplete; 6% of the material was not determined and a large number of substances present in small quantities only must have been overlooked. We note, however, the large amount of protein and this is a general phenomenon; just as we find life associated with protoplasm so we find protoplasm associated with protein.

It is clear that protoplasm must be a material, or rather a system of materials of very special nature since the enormous number of chemical reactions associated with life processes go on within it, and are apparently controlled and brought by it into proper co-ordination. Protoplasm also is concerned with the hereditary process, with the handing on to the male and female cells and from cell to cell in the body of the plant or animal, of the special qualities which cause the offspring to resemble their parents. (*See* CYTOLOGY.)

The modern theory of the special peculiarities of protoplasm associated with its life activities may be termed the *physico-chemical theory.* In this view stress is laid not so much on any special organization of the protoplasm as on its peculiar physico-chemical condition.

It is pointed out that proteins are colloidal in nature or rather exist in the colloidal state (*see* COLLOIDS) and that, on one hand, many of the peculiarities which distinguish chemical processes in the living organism from the same processes occurring in the laboratory, and the peculiar co-ordination of processes which marks the living cell—and indeed of the whole organism for the harmony of the working of the plant or animal body is a commonplace—are related in some way with the colloidal nature of the protoplasmic substratum in which they occur. It cannot be said, however, that the colloidal theory carries us very far. We know that material in the colloidal state exhibits an enormous extension of surface and that substances may accumulate on this extended surface (by a process known as *adsorption*) and react together at a much faster rate than would otherwise be the case. The theory, however, does not explain how the numerous chemical processes going on in the cell are on the one hand kept from interfering with one another, and yet on the other hand are brought into close interrelationship and co-ordination. Still less can a colloidal theory explain the even more complicated processes of *growth,* of *differentiation* (the development of new and different parts as the plant or animal develops), and of heredity. It is clear also that the protoplasm is not a simple colloid of two phases, such as are found in gamboge in water where the particles of gamboge are the one phase and the water surrounding them the other phase. In the protoplasm there is not only protein material but oily material (so-called lipin material) appears to be essential and probably also carbohydrates play a part. We know furthermore, that various salts (of potassium, calcium, etc.) are necessary. The physical relationship of the colloidal protoplasm must therefore be far more complex than that of any colloidal material studied in the laboratory. Any attempt to explain the peculiar relationship of the processes occurring in living organisms by reference to the behaviour of a complicated, dead, colloidal medium is largely speculation since the behaviour of such a medium is unknown.

Enzymes.—When dealing with the colloidal organization of the cell reference must be made here to the substances known as enzymes (*q.v.*). These are substances of unknown nature which can be extracted from dead cells whether plant or animal, and they must certainly play a very large part in the chemical processes going on in the living cell. They have three marked characteristics; they can act as catalytic agents, *i.e.*, they cause many chemical processes to go on at a much faster rate than would otherwise be the case; in chemical language they accelerate; they can thus cause rapid changes to occur which in their absence require a high temperature or the action of strong acids or alkalis. Secondly they act in very minute quantities and do not themselves appear to be used up in the process which they accelerate, for example invertase can break down 1,000,000 times its weight of cane sugar. Thus they partake of the nature of chemical catalysts Thirdly they are usually sensitive to heat (thermolabile) their activity being usually destroyed by temperatures well below that of boiling water. It is to be noted that the processes they accelerate may be either breaking down processes or building up (synthetic) ones, and that they can accelerate both such processes. Enzymes have been very actively investigated of late years especially by Willstätter and his pupils, but their nature is still obscure. They seem to be a part of the mechanism of the living cell by which the rate of various chemical processes are controlled. These enzymes seem to be of colloidal nature, or to have a colloidal carrier, though apparently they are not of protein nature; and furthermore their action is markedly *specific,* that is, the enzyme which affects the rate of one chemical process is unable to affect the rate of another process of marked chemical similarity. For example, sugars closely related in chemical composition require different enzymes to bring about changes in them. This is one of the puzzling aspects of cell physiology for it seems difficult to believe that the cell has a battery of enzymes to carry on the very numerous chemical processes with which it is concerned. Enzymes can, of course, only be studied outside the cell and it may be that the conditions in the living cell are different.

In relation to the cell organization it must be pointed out that many of the processes going on in the cell are *balanced or reversible reactions,* that is reactions which are capable of going in either direction; a good example of this is the formation of fats. These substances consist of glycerol (glycerin) combined with a fatty acid. In the presence of a special enzyme, lipase (found in castor oil seeds and in the animal body), this reaction is capable of going either way, the fat may be split up into glycerol and acid, or the acid and glycerol may be combined to form fat; the lipase accelerates *both* these processes. Whether the reaction goes in the direction of synthesis or analysis depends not on the lipase but on the concentration of the substances taking part, *i.e.*, fat, glycerol, fatty acid and water. It is probable that by controlling the amount of water available for particular reactions the cell is able to control the direction in which such a reversible process shall go.

WATER RELATIONS OF THE PLANT

It is well known that water is essential for all life processes. A seed may be thoroughly dried and still be capable of germination but it is in a dormant state; for its germination and ordinary activities water is necessary. It seems essential that the colloids of the protoplasm should be swollen (imbibed) with water in order that it may be active. Furthermore all the chemical processes of the cell go on in a watery medium and water is necessary for the solution and reaction of the substances concerned. The more active tissues of the plant generally contain particularly large quantities of water as was seen in the case of the green leaf; in the older and less active parts the percentage of water is less because many of the cells have been reduced to dead husks of cell wall material.

WATER RELATIONS OF THE CELL

As is shown above, under the heading of *Cytology,* the mature cell consists of a cell-wall lined inside with a thin layer of protoplasm, which itself encloses a central space, the *vacuole,* filled with cell sap. (*See* above, *Cytology.*) The sap contains various dissolved substances, sugars, nitrogenous materials, a variety of inorganic salts and other substances which are sometimes of colloidal nature. Curiously enough the majority of the substances are highly soluble in water and yet if a slice of beetroot is placed in water the amount of material passing out from the sap of the living cells is comparatively small as long as the cells remain alive; the cells on the other hand are capable of taking up water. We have then a peculiar condition of affairs in which water can enter the cell but the passage out of soluble substances present inside the cell is hindered. This effect is due, not to the cell wall which appears on the whole to be dead and inert, but to the living layer of protoplasm which is often known as the *plasma membrane.* This exhibits when living a condition of *semipermeability* since it lets water readily pass in and out, but hinders the passage of certain dissolved substances such as those in the sap. Water is attracted into the cell by the dissolved substances inside just as it would be into a sugar solution enclosed within a pig's bladder, which also roughly is semipermeable allowing water to enter freely but being more or less impermeable to the sugar. As a result of the entry of water the cell becomes swollen up and turgid and exerts what is known as *osmotic pressure* on the elastic cell wall or membrane which is thus stretched. Whole tissues of the plant are thus given a rigidity which is not due to their actual mechanical strength. The dependence of this rigidity on plentiful supplies of water is well seen in the case of leaves and the stems of herbaceous plants which often wilt, *i.e.,* become soft and flaccid, on a hot summer's day. Directly so much water is lost that the wall is no longer expanded, the rigidity of the cell must completely disappear.

Plasmolysis.—That the cell allows water to pass both ways and that the plasma membrane hinders not only the exit but also the entry of various substances into the cell is shown by the action on the living cell of a solution of cane sugar or of some salt such as potassium nitrate, or calcium chloride. If the living cell is placed in a solution of one of these substances of a concentration greater than that of the cell sap, water is drawn out of the cell and the cell collapses; this process is known as plasmolysis. It gives a convenient method of measuring the osmotic pressure of the cell. We find that concentration of cane sugar which brings about what is called "incipient plasmolysis," that is, the stage at which the plasma membrane has just begun to be withdrawn from the cell wall at one point. In this condition the osmotic pressure inside and outside the cell must be the same and since the osmotic pressure of the sugar solution can be determined the pressure of the cell sap is known. Osmotic pressure is generally expressed in terms of atmospheres; if a cell has an osmotic pressure of 5 atmospheres, the pressure exerted on a given area of the cell wall is five times as great as the downward pressure exerted by the atmosphere on the same area, which is about fourteen pounds to the square inch. Pressures of 5 to 40 atmospheres are common in plant cells and those of the order of 150 atmospheres have been observed. These pressures seem large but owing to the very small size of the cell the actual forces concerned are small.

Osmotic Pressure, Turgor Pressure and Suction Pressure.—When a cell is supplied with water it goes on absorbing and at the same time expanding with the result that the *backward* pressure of the stretched and elastic cell wall becomes greater and greater, until finally it equals the osmotic pressure of the cell contents; this backward pressure of the cell wall is known as *turgor pressure.* The cell is then fully expanded and fully imbibed and can absorb no more water. If on the other hand the cell is not fully imbibed the osmotic pressure is greater than the turgor pressure and the cell will tend to suck or draw water into the cell. When the cell is flaccid, as in the plasmolysed condition, there is no turgor pressure. It is clear that the difference between the osmotic pressure and the turgor pressure measures the pull with which the water is drawn into the cell; this difference is known as *suction pressure.* The term water absorbing power is sometimes employed but the first is by far the more satisfactory term since we are dealing with a pressure and not a power. If P = the osmotic pressure of the cell sap, T = the turgor pressure, and S the suction pressure, then $P-T=S$. We see then that the suction pressure is that fraction, if any, of the osmotic pressure left over from balancing the turgor pressure (backward pressure of the wall). When the cell is fully imbibed with water then $P=T$ and so $P-T=0$ and there is no suction pressure. When the cell is flaccid $T=0$ and therefore $P=S$, *i.e.,* the suction pressure is equal to the full osmotic pressure.

As the suction pressure is such an important quantity the question arises as to its measurement. As it represents the pressure with which water is drawn into cell from outside it is evident that if we just balance this pressure inside the cell by an equal pressure outside, the cell will neither take in nor give out water, and therefore will neither expand nor contract, *i.e.,* will remain unaltered in volume. This consideration is the basis of the method of measurement. The cell, the suction pressure of which is to be determined, is placed in purified paraffin oil under the microscope and its volume measured; this gives its normal volume since it does not absorb the oil nor does it lose water while immersed in the oil. The cell is then removed and placed in various strengths of cane sugar solution or some other plasmolysing agent until a concentration is found at which the volume is the same as measured in the oil. If the cell does not change in volume while lying in a watery solution it must be that its suction pressure is opposed by an equal pressure in the opposite direction. This counter pressure must be the osmotic pressure of the cane sugar solution which just keeps the cell at its original volume. The osmotic pressure of this solution thus gives the suction pressure of the cell in the state in which it was investigated; like the osmotic pressure it is usually expressed in atmospheres.

ABSORPTION OF WATER BY THE PLANT BODY

Water plants are surrounded by a very dilute solution of salts, as in the case of fresh water or a somewhat stronger solution in the case of sea water. Being surrounded by a watery medium the loss of water, and accordingly the need for absorption of water, does not play any very large part in their economy. The conditions are very different with land plants which, in the case of higher plants, often expose very large surfaces to the air and consequently lose great quantities of water in the form of vapour, which passes through the pores in their leaves in the process of *transpiration* (*see* below). Such land plants must therefore take up larger quantities of water from the soil and the rate at which they can take up water will depend upon the forces with which the water is held in the soil for it is these forces which the *suction pressure* of the cells in contact with the soil have to overcome.

Soil Conditions.—The soil is a very complex material consisting of (*a*) mineral particles of various sizes and varied chemical composition, (*b*) of organic matter usually in the form of a dark brown material known as *humus* which is derived for the most part from the decomposition of remains of dead plants which formerly grew upon the soil, (*c*) water, which is held by colloidal adsorption in films on the mineral and humus particles and also, to a certain extent, within spaces of the soil, (*d*) air which is found in the spaces between the soil particles. The air can, of course, be displaced by water, as in the case of a water-logged soil where all the pore spaces of the soil are filled with water. Soils differ very much in what is called their *mechanical* composition, *i.e.,* in the relative amount of particles of large and small size. A sandy soil has a large proportion of large particles, a clay soil has a large proportion of small particles, and to this is due their great difference in behaviour both in relation to water-retention and their response to mechanical treatment (*e.g.,* ploughing) and to fertilizers. The relation of size of soil particles to the water holding power of the soil is particularly important in reference to the physiology of the water absorption of the plant from the soil, and attempts have been made to estimate the relative forces with which the water is held by different soil constituents. Briggs and McLane working in America determined the amount of water held back by various soils when they were whirled round with enormous rapidity in a centrifuge;

the centrifugal force resulting from the rapid rotation at first causes water to be thrown off but it is finally balanced by the water retaining forces of the soil particles. By comparing the behaviour of a number of different soils of different compositions they deduced that if the water holding capacity (moisture equivalent) of the particles of size 2·0 to 0·05 mm. diam. (*i.e.*, coarse and fine sand) be taken as unity, the corresponding equivalent for the particles of below 0·05 to 0·005 mm. diam. (silt) is 12, while that for the particles of less than 0·005 mm. (*i.e.*, clay) is 57. The silt is partly colloidal, and the clay highly colloidal, and the high water-holding power is due to the colloidal properties. The humus also is of colloidal nature and of marked water-retaining power and its capacity in that respect may be taken as about the same as that of the colloidal clay. The forces with which the water is held in different soils and in the same soil with different amounts of water has been investigated by Shull by what may be termed a biological method. It is well known that dry seeds will take up water actively and often with considerable force, the amount they can take up depends upon the force with which the water is held in the medium from which it is being taken. The method consists then in placing dry seeds in different soils with different content and determining the amount of water taken up after a given period, say 48 hours. Similar seeds are then placed at the same temperature, (*a*) in concentrated solutions of lithium chloride and sodium chloride of high osmotic pressure, or (*b*) over sulphuric acid of different concentrations. If the seed takes up in the same time the same amount of water from a given soil as from the salt solution or from the moist air over sulphuric acid the water retaining power of the materials in which the seed is placed should be the same. Now the osmotic pressures of the solutions—which represent the forces against which the water-absorbing forces of the seeds are acting—are known and so the water holding power of the soil can be expressed in atmospheres. The results show that the water absorbing power of the seeds is very high, for they will take water from a saturated solution of lithium chloride which has an osmotic pressure of nearly a thousand atmospheres. They show also, as was to be expected, that in an ordinary loam soil the forces with which the water is held go up markedly as the water becomes reduced in amount. In a silty loam investigated the forces holding water were negligible when there was 20% of water in the soil, but when it was reduced to 15% the forces were several hundred atmospheres and when reduced to about 10% of the order of 1,000 atmospheres pressure. With sand the condition is very different for the material is non-colloidal and the water is only loosely held; only when the water content is reduced to a very small amount does the pressure become considerable.

Dynamic Relations of Water Absorption.—The observations which have been described above only gives us a picture of static equilibrium between the plant and the soil. They show what the conditions are when there is a balance between the forces pulling water into the seed (or root of the plant) and the forces holding the water in the soil, that is they show us the condition when water is no longer taken up. This, however, though helpful, as giving some measure of the forces which the root has to overcome, gives us a very imperfect picture of the relationship to the plant. The plant is continually giving off water in the process of transpiration and unless the rate of absorption keeps pace with the rate of loss of water the water content of the plant will begin to fall. The plant will flag when this difference in the two rates has existed for a short period and the plant will be dead long before the rate of absorption has fallen to zero. The equilibrium between absorption on the one hand and loss of water by transpiration on the other is thus, like the equilibrium in the living cell, a ***dynamic*** not a static one.

TRANSPIRATION

The term transpiration is applied to the process of loss of water vapour from the aerial part of a land plant; it is of the nature of controlled evaporation. The transpiratory losses take place mainly from the leaf surface since these organs expose a large surface for evaporation and are supplied on the epidermal surface with pores known botanically as stomata. (*See* above, *Anatomy*.) These pores interrupt the otherwise continuous layer of *cuticle* which covers the surface. In its absence the loss of water from the leaf surface would be very large and uncontrollable. The cuticle is, however, not completely waterproof so that we can distinguish ***cuticular*** transpiration and *stomatal* transpiration. The second is very much the larger, being usually 80–97% of the whole, though under special conditions, as in a tropical rain forest, the cuticular transpiration may be as high as the stomatal.

Measurement of Transpiration.—That transpiration occurs can be shown by the loss of weight of a potted plant, when the pot and surface of the soil are protected from water-loss by rubber sheeting; this gives a convenient method for measuring the rate of transpiration. It is not applicable to plants growing in the ground; for such plants paper dipped in a cobalt chloride solution, dried and applied to the leaf may be employed. On the absorption of the water vapour coming from the leaf the colour of the cobalt chloride paper changes from pink to blue, and the rate of this change gives some measure of the rate of transpiration.

Size and Arrangement of Stomata.—The stomata are more commonly confined to the lower surface of the leaf—the cuticle on the upper surface being then continuous, though leaves with stomata on both sides frequently occur. The stomata are very small pores, those of the sunflower lead being about $\frac{1}{100}$ of a millimeter (*i.e.*, about $\frac{1}{2500}$ of an in.) in diameter. They are very numerous, varying from 40 to 300 per square mm.; a sunflower leaf may thus bear 13,000,000 of them. The pore is bounded by two special cells known as *guard cells* (as described in the anatomy of plants) and open below into a chamber which is bounded by the walls of the green cells (*mesophyll*) of the leaf. These cells are full of water and from their wet cell walls water naturally evaporates into the space, and by the physical process of gaseous diffusion passes out of the stomatal pore into the drier air outside. As the stomata occupy a very small proportion of the total surface it might be supposed that the rate of passage of a gas or vapour out or in would be very slow. It was shown, however, by Brown and Escombe in 1900 that such very small pores allow of a much greater rate of diffusion than might be expected. It is found that provided the pores are not too close to one another the rate of diffusion is proportional to their diameter and not to their area.

Effect of Various Conditions on the Rate of Transpiration.—Transpiration like most physiological processes is markedly affected by external conditions. Since the process is essentially one of evaporation, one of the most important factors (the term factor is applied to a particular condition affecting the rate of a process) is the humidity or relative dryness of the air to which the plant is exposed. The drier the air the more rapid, on purely physical grounds, will be the rate of diffusion of the water vapour through the stomatal pore. This is due to the big difference of the water content (humidity) of the air below and above the pore. The proper measure of the evaporating power of the air is not the actual relative humidity (or percentage saturation of the air) but the *saturation deficit* and this is markedly affected by temperature. Air 70% saturated at 10° C has only about half the saturation deficit of air 70% saturated at 20° C, and so its evaporating power is only half. Temperature itself has very little effect on transpiration or evaporation except in so far as it affects the evaporating power of the air. Atmospheric pressure has only a slight effect since evaporation tends to go up with a fall in barometric pressure but it is so small that it can under ordinary conditions be neglected. Wind is a very important factor in transpiration. It is well known that plants suffer very much in windy situations and "wind-breaks" are often put up for plant protection. The ill effect is mainly due to the enhanced rate of transpiration, which is the direct physical effect of the removal by the wind of the layers of air in contact with the leaf.

Effect of Light.—If the rate of transpiration is measured, say by weighing a potted plant under appropriate conditions, it is found that the water loss is much greater by day than by night and this occurs even if the evaporating power of the air and the temperature are kept constant. It is a well known effect of light upon the higher terrestrial plants. This effect occurs in an ordinary diffused light so it cannot be due to the heating effect of the rays, for in such circumstances such effect is practically negligible. The effect produced by the light must be due to some change in the leaf itself since the factors affecting evaporation have remained unaltered. As the transpiratory water loss is through the stomata we should expect some change in the size of the pore, and it is found that in the majority of leaves light causes a widening of the stomatal pore and darkness a partial closure.

Stomatal Action.—As already stated the stomatal pore is bounded by two guard cells and it is by changes in their shape that the alteration of the pore is brought about. Their shape, the relative thickness of their inner and outer walls, and their attachment to the epidermal cells are such that when they become more turgid their inner walls—those facing the pore—move apart and so the pore widens, while on a reduction of turgor these walls approach one another and the pore becomes less in size. When the cells become collapsed, as in drying or by plasmolytic agents, the size of the pore is very much reduced though probably not to zero.

The mechanism by which light brings about alterations of turgor in the guard cells has been much disputed. It has often been held that the stomata open in light owing to the increased turgor due to the accumulation of sugars produced by the assimilatory activity of the chloroplasts of the guard cells. This view is quite untenable for the guard cells open in the light in the absence of external supplies of carbon dioxide. Lloyd (1908) also has shown that guard cells containing only leucoplasts behave similarly to normal ones. It was shown also by the same observer that the guard cells in the early morning, when the pore is closed, show much starch, which disappears during the day to reappear again in the evening when the stoma closes. This led to the view that the light affected the starch-sugar ratio in the guard cells. In the day insoluble starch would change into soluble sugar and the turgor of the cell rise, in the night the sugar would change back to starch and the turgor fall. The turgor changes would bring about the corresponding changes in the size of the stomatal pore. This view received support from the observations of the osmotic pressure of guard cells. In *Rumex patientia*, for example, it was found that the osmotic pressure of the guard cells is 23 atmospheres when they are fully open, about midday, while only 13–14 atmospheres when the pore is closed at night. It is found that in addition to light other factors such as neutral salts and acids and alkalis affect the starch-sugar relation and so stomatal movement. This is rather what might be expected since the change from starch to sugar and the reverse is almost certainly an enzymic one. Further work by G. W. Scarth in 1926 indicate that acetic acid and ammonia, *i.e.*, both acid and alkali, will cause the opening of the stomata; in an intermediate range where there is slight acidity the guard cells remain closed. This suggests that what the guard cells respond to is a change in the concentration of free hydrogen ions (*i.e.*, the free hydrogen parts of the acid molecule when it is dissociated in water) of the solution. In this view light affects the "acidity" of the leaf as a whole either by altering the content of organic acids in the cells, or the concentration of carbonic acid by affecting the rate of assimilation. There are indications that the effect is more complex and that *the change in the starch-sugar ratio is too slow to explain* the rapid turgor changes that occur. It is probable that there is present in the cell sap of the guard cells some colloidal material which absorbs water and that the amount of water the colloid takes up is altered by changes in the concentration of the hydrogen ions of the cell.

Control of Transpiration by Stomata.—The question of the control of the rate of transpiration by the stomata has also been much debated. The older view was that the opening and closing of these pores had an important controlling effect. This view was abruptly called in question by Lloyd in 1908 who denied the regulation of water loss of leaves through stomatal closure. It is clear from later work that the stomatal aperture may vary widely while the rate of transpiration shows no corresponding change; thus the stomata may go on opening in the middle of the day while the transpiration rate falls. The matter is again complicated by the fact that the rate of loss of water vapour by the stomata is also affected by the accumulation of moist layers of air upon the surface of the leaf. If the stomata open more widely when such layers are present there may be little possibility of any faster diffusion of water vapour through the pores. Calculations indicate that in still air the layers of moist air on the leaf exert the most effect, and it is only when the stomatal pores have become very narrow that the pores can have a controlling action. In wind, however, these moist layers are removed and the stomatal pore can exert a controlling action at any degree of opening. It must be borne in mind however that the stomata are very sensitive to light but their response to losses of water by the leaf are slow, so that they cannot keep the water content of the leaf constant by controlling the stomatal pore.

Direct Action of Light on Leaf Cells.—As already described light markedly increases transpiration by causing the stomata to open, but the question arises as to any possible direct effect on the mesophyll. It was claimed by Francis Darwin (1914) that in a leaf which had been vaselined on both sides, to block the stomata, and then slit so that the mesophyll cells transpired directly into air, light still increased the rate of water loss by as much as 36% in the case of the leaf of ivy. Such a huge increase seemed very unlikely, so the matter was again investigated by Henderson (1926), who showed that, when all allowances were made for possible changes of temperature, light did produce an increased rate of evaporation from the mesophyll cells of the leaf to the extent of about 5%. The exact mechanism of this is obscure; it is probably some effect on the resistance of the protoplasm to the passage of water through it to the surface of the cell. In the light the cell wall would be more fully imbibed, *i.e.*, wetter than in the dark.

Advantages and Disadvantages of Transpiration.—This question is often debated, the extreme positions being (1) that the process is an *unavoidable evil*, (2) that it is a *physiological necessity*. The idea of its physiological necessity is mainly based on the view that the water and the inorganic salts that the plant requires are taken in together in the form of the very weak solution which occurs in the soil, and that the excess water must be got rid of in transpiration. This view is based on the erroneous assumption that water and salts enter the plant together. As a matter of fact the forces bringing about the entry of water and the entry of dissolved salts into the root cells are of an entirely different nature; the two must enter quite independently. Whether transpiration is an "evil" may be debated but it is perfectly clear that given the necessity of taking in gases from the air, the loss of water by plants is quite unavoidable. The same pores which allow the entry of gases must also allow of the passage out of water vapour. The plant could only stop such water loss by having a continuous cuticle, and then the supply of carbon dioxide for the manufacture of sugar and starch would almost completely be cut off. *The loss of water by transpiration is a necessary result of the construction of the plant.* It has been suggested that a rapid stream of water rising in the wood (*see* below) is necessary to convey the salts to the leaves, but it is found that a reduction of transpiration does not necessarily reduce the accumulation of salts in plants. It may be that some *minimum* rate of upward water flow is necessary to transport the salts to the higher parts of the plant. Transpiration may also play some small part in keeping down the temperature of plants exposed to the direct rays of the sun.

MOVEMENT OF WATER IN THE PLANT BODY

The water that enters the plant from the soil ultimately escapes from the leaf surface passing through the stomatal pores in the form of water vapour. The question arises as to the path taken by this water. It has been known a long time that the main body of the water passing through the vascular plants travels by way of the xylem, *i.e.*, the wood. (*See* above, *Anatomy*.) The evidence for this is various. It is found that if the trunk of a tree is "ringed," *i.e.*, cut through right down to the wood throughout the circumference of the tree, water continues to pass up the tree for a long time and apparently unhindered. Again if cut shoots are placed in a solution of a dye such as eosin, the wood alone is deeply stained showing that the dye solution has travelled up through this tissue. The frequent occurrence in the wood of wide open tubes containing no protoplasm also indicate its function as a conducting channel.

Passage of Water Across the Root.—The root as anatomical studies show, usually exhibits elongated outgrowths from certain of its superficial cells. These outgrowths are known as *root-hairs* and serve to increase the surface of the root available for absorption. These hairs are in contact with the films of water on the soil particles and they can withdraw water from the soil if their suction pressure (*see* above) is greater than the imbibition forces of the soil, *i.e.*, the forces tending to retain the water in the soil. The water thus absorbed, if it is to reach the leaves, must pass across the root to the xylem strands and the question arises as to the mechanism of this transport. It has been shown by the work of Ursprung and Blum that there is a *gradient of increasing pressure* from the root hair to the endodermis; by this means the water will pass from cell to cell across the cortex. At the endodermis there appears to be some abnormal condition for in the absorbing root of the broad bean it is found that while the suction pressure rises from outside to the sixth cortical cell from 0·7 to 3·0 atmospheres, yet at the endodermis it falls to 1·7 atmospheres; as a result the direction of movement of the water should be reversed and the water pass back again; this cannot be the case so the matter requires further investigation.

Ascent of Water in the Wood.—That the water rises in the wood to supply the needs of transpiration is well established, but the mechanism of this rise has been much disputed. It is clear that any explanation must meet the extreme case of the tall leafy tree. Now a single tree may lose many gallons of water a day in transpiration and a blue gum tree (Eucalyptus) of Australia or a Sequoia of N. America may reach a height of 300 ft. or more. A mechanism has thus to be found which will not merely hold up a column of water at a height of 300 ft.—this is merely a problem in statics—but one that will drive (or pull) many gallons of water a day to this height. Many different forces have been invoked to explain the rise. The force of capillarity has been called in but measurements of the size of the wood vessels show that capillarity will not explain the rise of water to the height of a tall tree, let alone the continued movement of the water upward. Then again atmosphere pressure has been suggested as concerned in the movement, but such a pressure would only explain the rise of water to a height of a little over 30 ft. "Root pressure" has been called in as the motive power for the rise of the transpiration stream. When the stem of a wood plant is cut across near the ground a flow of sap under considerable pressure may occur from the wood of the cut stump; the pressure bringing about this flow is known as root pressure. Unfortunately for this explanation no pressures have been observed which are adequate to explain the rise of water to the top of a tall tree. Again root pressure is found most active in the spring, while the transpiration stream flows most actively in the summer. Then again we have the so-called *vital theories* of the cause of the ascent of sap in all trees. In these theories the living parenchyma cells which are so characteristic of the wood are supposed to exert a pumping action. They are assumed to take water from a lower wood vessel and pump it into a higher vessel with which they are in contact.

The objections to these vital theories are mainly twofold; they are inconsistent with experimental data and also with the known structure of the wood. The strongest experimental evidence against vital theories is obtained from the results of poisoning experiments. E. Strasburger carried out in 1893 some classical experiments with an oak tree over 70 ft. high and with tall climbers like wistaria and hop. The oak was cut off at the base and the cut end placed in a tub of picric acid, a highly poisonous yellow solution, which was found to be taken up in considerable quantities. After three days in this fluid the trunk was placed in a solution of a reddish dye (fuchsin) and there left for another six days. The oak trunk was then split down the middle when it was found that the yellow poison had been drawn up to 70 ft., and among the yellow stained wood were red patches showing that the dye had been drawn up *after* the picric acid, *i.e.*, through the *dead* wood. In the case of the two climbers lengths of 30–40 ft. were killed by heat when it was found that, as in the oak, coloured solutions were drawn up through the stems in spite of the killing of the living cells. These experiments seem to show clearly that fluids will rise in the wood of tall plants without the intervention of the living cells of the wood.

Cohesion Theory of the Ascent of Sap.—It is evident that in the absence of a pumping mechanism in the wood itself the water rising must *either be pushed from below or pulled from above*. Since water will rise even in tall trees when they are severed at the base some pulling force from above would appear to be acting and it can be demonstrated that a cut leafy shoot does exert a pulling or sucking force on a column of water. If a glass tube is fixed with an airtight junction to the lower end of a small leafy branch of a tree (the wood being bared at the point of junction), water will naturally rise in the tube. If the tube is filled with boiled water and the lower end placed in a dish of mercury, the mercury will be drawn up after the water. Under favourable conditions when no air bubbles develop in the system the mercury column will be raised *to a height above that of the barometric column*. This demonstrates that the cut branch exerts a definite sucking force on the water column. The same fact could be demonstrated without mercury using water alone in the tube, if the space above the water in which the tube dipped was exhausted of air. More elaborate experiments of this type show that a transpiring branch will exert a pull of 7 to 8 atmospheres. Such experiments demonstrate not only the sucking force exerted by a cut leafy shoot but also a peculiar physical property of a fluid such as water and mercury, namely, its cohesion or tensile strength. If a column of water or mercury is held up in a vertical tube without being supported from below, it must evidently be held by a pull from above. If, however, the fluid is transmitting a pull its particles must cohere together like the particles of a steel wire. Now it is found that if a fluid, like water, be free from air bubbles and is enclosed in a rigid tube to the wall of which the fluid *adheres*, it can then transmit a very considerable tension, owing to the attraction of the water particles for one another which is spoken of as their *cohesion*. Under conditions spoken of, with the fluid adhering to the walls of a rigid tube, the fluid is unable to change its shape and hence, as the result of its cohesion, is able to transmit a pull like a steel wire. By experiment it has been shown that in the case of water this cohesion or tensile strength is very great, for it requires over 200, and probably over 300, atmospheres to rupture a column of water.

The cohesion theory of the ascent of sap asserts that the water threads in the water channels of the wood are adhering to the wet walls of these vessels (and of the tracheids) and that these water threads can transmit any pull exerted on them at the top. Any cross-walls in the wood channel do not interfere with the practical continuity of the water columns since these walls are fully soaked with water. As has already been explained transpiration losses take place from the cells abutting on the intercellular spaces in the leaf, with a consequent increase in their suction pressure. As a result they take water from neighbouring cells and those with rising suction pressure will take water from the tracheids found in the fine vascular bundles (veins) of the leaf. The water columns in these dead tracheids are continuous with those in the rest of the wood channels in the plant, and the result of the withdrawal of water by the leaf cells is that these columns fall into a state of tension which is transmitted throughout the plant and thus down to the roots. The pull of the mesophyll cells in the leaf is thus felt by the cortical cells of the absorbing root, and water is drawn from them into the wood and their suction pressure goes up. This leads to water being taken from cells farther and farther towards the outside of the root, and so to loss of water from the root-hair which takes water from the soil; thus the chain of cohering particles extending from the soil to the leaf is complete.

Difficulties in the Cohesion Theory.—The cohesion theory certainly provides the most satisfactory explanation of the rise of the transpiration stream in tall trees. There are one or two difficulties, however, presented by the theory, one of which is in respect of air bubbles in the woody tracts. If sections of the wood are cut with great precaution a certain number of the wood channels are always found to contain air bubbles and therefore to be out of action. If the number of these air-containing channels went on increasing from year to year the proportion of blocked channels might be very high, though the new ring of wood laid down each year would start without air bubbles. It is suggested by Dixon that root pressure which develops in the spring would compress the air bubbles, by pushing the columns from below, and so cause their solution. It is doubtful, however, if root pressures occur of the magnitude necessary to bring about the solution of the bubbles at the top of a tall Sequoia tree. On the other hand the bubbles found in sections of the wood may be artefacts, *i.e.*, produced in the cutting of the sections. From the observations of H. R. Bode it seems doubtful if bubbles exist at all in the water-conducting tracks of herbaceous plants under normal conditions, and the case may be the same in woody plants, though the bubbles seem to develop very easily; this question of air bubbles in the wood requires further investigation. Another difficulty lies in the behaviour of dead leaves. The cohesive theory it must be remembered is a *purely physical* theory. All it requires is one membrane evaporating into dry air, another membrane in contact with a water supply, and the two connected by a continuous water thread under such conditions that it can support a tensile stress. Accordingly if we kill a leaf with chloroform vapour while still attached to the plant it should continue to draw up water as its cell walls are still directly continuous with the water supplies of the stem. One would expect the leaf cells to collapse owing to the loss of osmotic pressure but not to dry up; we find, however, that such a dead leaf soon dries. This suggests that though the cohesion theory rightly envisages the main factors in the rise of water there are other subsidiary factors which play a part.

ABSORPTION OF SALTS AND PERMEABILITY

As is well known the plant contains considerable quantities of inorganic salts of sodium, potassium, calcium, magnesium and iron and the only source of these is the soil from which nitrates, sulphates and phosphates are also obtained. The water in the soil is not pure but is a weak solution of inorganic salts known as the *soil solution*. The exact composition of the soil solution is doubtful. It must vary much from soil to soil and from time to time in the same soil and it is a matter of great difficulty to separate it from the soil. Estimations give a concentration of total solids in the soil solution from a wet soil of 0·1 to 0·025 per cent or less; a manured soil gives a stronger soil solution than an unmanured one. It is from the soil solution that the ordinary land plant takes up the salts necessary for its growth; unless the essential salts can be supplied in sufficient quantity growth will suffer. It must be added however that a sufficient supply of water and appropriate salts together with a sufficient aeration of the root system are not in themselves sufficient; in addition, the reaction of the soil must be suitable. The soil must be neither too acid nor too alkaline, or to put it more accurately, the concentration of hydrogen ions in the soil must be correct. Olsen (1923) in studying Swedish vegetation demonstrated a remarkable agreement between the concentration of hydrogen ions in the soil and the distribution of various plants. The presence of lime or chalk in the soil is of great importance in relation to soil reaction since lime neutralizes acidity. The addition of lime will often raise an infertile "sour" soil to a fertile level. The striking response of some plants to lime-rich or lime-poor soils may be related to the hydrogen ion concentration of the soil.

The Essential Salts.—Plants which normally grow in the soil can be grown successfully in water cultures, *i.e.*, in a solution of salts, or in quartz sand watered with such a solution. A solution of this kind may consist of water 1,000 grams, potassium nitrate 1 gm., calcium sulphate 0·5 gm., magnesium sulphate 0·5 gm., calcium phosphate and ferric phosphate each 0·25 gm. In this or similar solutions plants may be grown successfully for many generations. If any of the elements, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium and iron are absent, the plant suffers, indicating that these elements are essential to the plant. The sodium and chlorine which plants absorb from the soil do not seem to be essential for plant growth. Moreover, small quantities of boron are absolutely necessary for the proper growth of such a plant as the broad bean. We know, in addition, most of the essential salts appear to be poisonous when given alone and that salts have an *antagonistic* action to one another, each neutralizing the toxicity of the other. The culture solution has thus to be a *balanced solution* in which the various toxicities cancel out.

Absorption of Salts.—When the water relations of the cell were discussed it was pointed out that the plasma membrane of the cell was of a semi-permeable nature, in that it held back soluble substances in the cell sap while showing a permeability to water. The fact that plants contain inorganic salts which they have taken up from the soil shows that the cell is not completely impermeable to dissolved substances, as does the fact that such substances as sugar travel about the plant. It is found, as we should expect that when salts (such as potassium nitrate or sodium chloride), or even cane sugar, are used as plasmolysing agents that the substance enters sooner or later and plasmolysis disappears. The entry of salts into the cell raises the whole question of the nature of the living plasma membrane and the forces which are concerned in bringing about the passage of substances in and out of the living cell. The subject, however, is as yet a very confused one and has recently been reviewed by Stiles. On simple physical principles a salt should go on entering and accumulating in a cell until the concentration inside and outside the cell is the same. If, however, a slice of carrot is placed in a solution of potassium chloride the salt goes on accumulating in the cell until the concentration inside is apparently many times (even 25 times) that outside. Again as Osterhout has shown, if the sap of the large cells of the seaweed *Valonia* is analysed it is found that the concentration of potassium inside the cell is over 40 times that of the sea water outside. On the other hand the concentration of sodium is five or six times as great in sea water as it is in the cell sap. The fact that the living plasma membrane can keep permanently between its two sides so great a difference of concentration as that of potassium shows that it must be of very peculiar nature.

Changes of Permeability.—As might be expected from the fact that the accumulation of substances in a cell is a fluctuating quantity one finds that the permeability of a cell is not constant; in other words the rate of entry or exit of a given substance may be changed by external conditions. For example the permeability of a cell to a particular dye may be markedly affected by the nature and concentration of a neutral salt in the dye solution. Since the plasma membrane contains a high percentage of protein and the physical condition of such substances is altered by many salts, the change in permeability is not unexpected. Then again we find that the rate of entry of one salt into a cell is altered by the presence of another salt. Weak solutions of sodium chloride and calcium chloride, which by themselves do not plasmolyse a cell, will do so when mixed. The effect seems to be due to the calcium ion altering the membrane in such a way as to hinder the entry of the sodium ion—another example of antagonistic action. Again it has been claimed that light increases the permeability of the cells in the leaf of the lime. Illumination has been definitely shown (Brooks, 1927) to increase the rate of entry of a dye into the *Valonia* cell, and also to increase the rate of diffusion of the salts from the cut surface of a tissue, such as that of the swelling at the base of the leaf-stalk in the sensitive plant (*Mimosa*). We have probably to view the permeability of active cells as constantly varying, though how the changes in permeabilities of neighbouring cells are related so as to cause material to travel in any particular direction in a tissue is still obscure.

Transport of Salts and of Organic Substances.—The mechanism of the transport upward of mineral salts and the transport downwards of organic substances (such as sugar from the leaves), is still imperfectly known. Owing to the apparent slowness of diffusion of salts from cell to cell the supplies of salts required by the leaves would seem necessarily to move in the transpiration stream. There are, however, no data available showing that the rate of the stream and the concentration of salts in it are sufficient to transport the necessary supplies. A reduction of the rate of the transportation stream by shading leaves does not appear to reduce the salt content of the plant, at least in the herbaceous plants investigated. It may be that a certain critical rate of the stream is required and that in the experiments mentioned the rate was always above this.

GENERAL METABOLISM OF THE PLANT

The term metabolism is applied to the whole complex of chemical changes going on in the plant, the building up of more complex organic substances from simpler ones being spoken of as *anabolism,* and the breaking down of complex to simpler ones being termed *katabolism.* It has already been noted that very many of the chemical reactions in the plant are balanced or reversible ones, so that according to the conditions (*e.g.,* the concentration of the reacting substances) the process may at one time be anabolic, another time katabolic. A balanced reaction ultimately reaches an equilibrium point where the rate of the process in one direction is equal to the rate in the other; the equilibrium is thus a dynamic one. In those balanced reactions in which there is an energy exchange, *i.e.,* heat is taken in or given out, the equilibrium point is altered by a change of temperature. Experiment in the laboratory shows that the rate of many chemical processes is markedly affected by a rise of temperature, the rate of many of them doubling for each rise of 10° C. The marked effect of temperature on the metabolism of plants is no doubt partly one of acceleration, and partly a shifting of the equilibrium points of reversible reactions. There is a further point in relation to balanced reactions; if such a reaction is proceeding in a particular direction and material A is being converted into material B, then the mere accumulation of B tends to slow down the reaction and ultimately brings it to a standstill; should then the amount of B be increased further the reaction will proceed in the other direction, *i.e.,* from B to A. A similar result is very common in reactions caused by enzymes, the accumulation of the products of the reaction tending to bring the reaction to a standstill.

Stress must be laid on the fact that the chemical processes going on in the living plant take place not in a simple homogeneous medium like water but in the protoplasm, which is what is called a *heterogeneous system,* having many colloid phases. (*See* above.) The enzymes which seem to play so large a part in metabolism also appear to be colloidal at least in part; thus many of the reactions may take place on their surfaces and on the surfaces of the protoplasmic medium. The system in which the chemical changes occur being thus heterogeneous and of so complex a nature, we should naturally expect that a variation of conditions (such as of temperature, illumination, etc.) would affect differently the processes in the plant and similar processes occurring in the laboratory.

The metabolism of the green plant, to which our brief review must be confined, shows two main anabolic processes, (*a*) the manufacture of carbohydrates in the process of *photosynthesis* (*carbon assimilation*), (*b*) the building up of complex nitrogenous substances such as proteins from nitrates absorbed from the soil and from organic material such as carbohydrates. In addition there is a main metabolic process, that of *respiration,* which is akin to the process of alcoholic fermentation by yeast.

PHOTOSYNTHESIS (CARBON ASSIMILATION)

The whole life of the globe is dependent on this photosynthetic power of green plants for they alone are able to manufacture food material for themselves. The green plant may be described as the great alchemist which alone of living things has mastered the secret of converting the sun's rays into food material. The process of assimilation is associated with certain pigments which absorb the incident light; the energy so obtained is employed in the building up of complex organic substances from carbon dioxide and water, oxygen being at the same time evolved. In the case of the higher plants the pigments of the green leaf, as we know mainly from the work of Willstätter and his collaborators, are four in number—*Chlorophyll a,* $C_{55}H_{72}O_5N_4Mg$, a blue-black crystalline substance, greenish blue in solution; *Chlorophyll b,* $C_{55}H_{70}O_6N_4Mg$, a green-black substance, green in solution; *Carotin,* C_4OH_{56}, an orange-red substance found also in carrots, and *Xanthophyll,* $C_{40}H_{56}O_2$, a yellow substance. The two first are the green pigments and are often termed "chlorophyll," the other two are the yellow pigments. The amounts of these do not vary greatly in different leaves. The average amounts are given below:—

	Percent of fresh weight	Percent of dry weight
Chlorophyll a . . .	0·2	0·63
Chlorophyll b . . .	0·075	0·24
Carotin	0·017	0·05
Xanthophyll	0·033	0·09

In green algae the same four pigments are present; in the brown and red algae and blue-green algae chlorophyll is present in association with other pigments which give these plants their peculiar colour. The assimilating pigments are not dissolved generally in the cell but are associated with denser portions of the protoplasm of definite form, known as plastids; it is apparently in these plastids that the special physical and chemical processes characteristic of photosynthesis occur. It is generally accepted that the two green pigments are the most important in the process of photosynthesis. One of the functions of the green pigments is clearly that of absorbing the necessary energy for the decomposition of carbon dioxide, and their solutions show very characteristic absorption bands, particularly in the red-orange and the violet end of the spectrum. Whether in addition the chlorophyll reacts chemically with the carbon dioxide is still in doubt. Willstätter and Stoll hold that the carbon dioxide combines with the chlorophyll to form a definite compound on which light acts; it is thus converted into a substance of the nature of a peroxide which can be acted upon by an enzyme.

Products of Photosynthesis.—Sachs (1862) was the first to relate the carbohydrates appearing in the leaf to the process of assimilation; he was responsible for the dictum that starch was the "first visible product of assimilation." This was based on the fact that in the case of many plants starch appeared in the plastids of the leaf in the light and disappeared again in the dark. It is now generally agreed that carbohydrates of some kind are the main products of photosynthesis, though many monocotyledons form little or no starch, but much sugar in the form of glucose, fructose and cane sugar. Which carbohydrate is first formed is a matter in dispute. In green leaves exposed to light cane sugar accumulates markedly; this has led to the view that it is the first formed sugar. A much more plausible hypothesis would seem to be that hexose sugars (glucose and fructose) are first produced, and that when these reach a certain concentration cane sugar is formed from them; this view is supported by the work of Weevers (1924). The starch arises in all probability from glucose and it would seem likely that there is a critical concentration of sugar in the chloroplast above which starch is formed from the sugar, and below which the starch is converted back into sugar. This is confirmed by the fact that by floating leaves on sugar solutions of high concentration even those which are normally starch-free will produce that substance in their chloroplasts.

Effect of Various Conditions on the Rate of Photosynthesis.—The rate of this process is affected by the concentration of carbon dioxide available, by the amount of water, by the intensity of the light and by its wave length, by the chlorophyll content, by the supply of oxygen and of mineral salts, and also by many other internal conditions, or factors as they are called. It used to be supposed that all these factors acted independently, but it was shown by the work of F. F. Blackman (1905), that the factors are closely interrelated. He put forward the "theory of limiting factors," that in any set of conditions the rate of a physiological process was determined by the factor present at the lowest intensity. The view that under any set of conditions it was only by the increase of the intensity of one factor that the rate of the process could be increased requires some modification in the light of recent work. It is clear, however, that if any factor A is present at very low intensity it will prevent an increase of another factor B having the marked effect upon the rate of the process which it would have produced if the factor A were acting at a higher intensity. Bearing this relationship of the factors in mind, we find that with increasing concentration of carbon dioxide the rate of assimilation goes up proportionally, if the concentration is not too high and light and temperature are sufficient. Similarly with increasing light-intensity the rate of assimilation goes up proportionally if the temperature and concentration of carbon dioxide are sufficient. With high light intensities there is probably a falling off in the rate, as with higher concentrations of carbon dioxide. With a moderate temperature, if other conditions are favourable, the rate of assimilation obeys the Van't Hoff rule, approximately doubling for each rise of temperature of 10° C. At higher temperatures, somewhere in the neighbourhood of 25° C, with some plants, the injurious effect of high temperature appears and the rate begins to fall off. The process of assimilation is little sensitive to the concentration of oxygen, reduction to $\frac{1}{100}$ of the normal amount having no effect, but complete absence of oxygen acts injuriously. A number of *internal* factors must markedly affect the rate of photosynthesis, but the only one that has been closely investigated is that of the chlorophyll-content, by Willstätter and Stoll. It was found that the photosynthetic rate per unit of chlorophyll (the "assimilation number") varied markedly in different plants and even in the same plant. Leaves of yellow varieties were found to show very high rates in proportion to the amount of chlorophyll present, though the rate in these leaves is less influenced by temperature than is that of fully green leaves. Clearly there is some internal factor (or factors) other than chlorophyll content which is controlling the rate. This may be termed the "protoplasmic factor"; Willstätter and Stoll conclude that this factor is enzymic.

Quality of Light and Photosynthesis.—The question of the effectiveness in photosynthesis of light of different wave lengths has been hotly debated by physiologists for many years. The question is a complicated one since in white light there are great differences in the energy-value of the rays of different wave lengths, and the different rays are absorbed to a very different degree by the chlorophyll and the colourless parts of the leaf. In the case of the leaf there is little doubt that with equal intensity of incident light the red rays are more effective than the blue. The work of Warburg and Negelein quoted below indicates also that for equal quantities of light-energy *absorbed by the chloroplast,* the red rays are considerably more effective than the blue.

Efficiency of the Photosynthetic Process.—It is known that the green leaf is comparatively inefficient as a producer of assimilation material. Brown and Escombe (1905) attempted to determine the efficiency of the green leaf by comparing the energy of the light absorbed with the absorption of carbon dioxide, the assumption being made that glucose was produced in the leaf from the carbon dioxide. Their results are only very approximate but they indicate that the efficiency is only about 1%, increasing however with low intensities of light to about 4%. A large proportion of the energy absorbed is used in transpiration, and with the higher intensities of light the concentration of carbon dioxide in nature is too low to allow of the light being fully effective. The most accurate experiments on the efficiency of the photosynthetic process are those of Warburg and Negelein (1922 and 1923) with the minute unicellular fresh water alga, *Chlorella.* With such a plant there is no question of transpiration, and the experimental arrangements were such that practically the whole of the light received was absorbed by the chloroplasts of the cells; in the case of the leaf a considerable amount of the light passes through it and a certain amount is reflected. Warburg and Negelein show that with decrease in the intensity of the light the efficiency goes up, *i.e.,* a larger proportion of the light absorbed is made use of in photosynthesis, the rate of the latter process being measured by the production of oxygen. In their earlier experiments they obtained an efficiency of 71% when using yellow and yellow-red rays; the methods employed for calculating this were, however, not altogether satisfactory. In their later work they obtained results of 59% for red light, and 34% for blue light. Whether these percentages are the maxima that can be obtained is not yet certain.

Cosmic Relations of the Photosynthetic Process.—As already stated this process is the fundamental chemical process on which the life of all animals and plants depend. A study of the land plant's relation to the sun shows it as a machine of comparatively low efficiency, since only a small part of the sun's energy is stored by the plant, crops such as cereals and potatoes retaining only 2 to 3% of the energy received. This uneconomical working is in part due to the fact that so much of the sun's energy consists of invisible heating rays which the plant cannot use for food production. Furthermore the plant is somewhat more efficient than first appears as part of the material manufactured during the day is burnt up again in respiration and so lost. The proportion so lost is very variable, depending largely on the temperature at night; it may be taken as 20–50 per cent. Another cause of the low efficiency of the plant, as has already been pointed out, is the low concentration of the raw material (the carbon dioxide) available for the process. It has been suggested that in early Carboniferous times when coal was formed, the concentration of this gas was higher. However this may be it is clear that the energy available from our rapidly lessening stores of coal and oil is really the energy of sunlight received by the earth many thousands of years ago.

RESPIRATION AND FERMENTATION

Respiration and fermentation are closely allied processes. Both consist in the breaking down, generally by an oxidation, of complex organic compounds, commonly sugar, into simpler ones with a liberation of energy. In respiration oxygen is usually necessary and the breakdown is complete, carbon dioxide and water being formed. In the second oxygen is not necessary and the chemical degradation is not complete, some organic substance such as alcohol being the end product. As is to be expected the release of energy for a given amount of sugar consumed is much greater in respiration than in fermentation, the first being a much more economical process than the other. By means of these two processes the plant gains supplies of available energy from the food material consumed. Such supplies of energy are necessary to maintain the dynamic equilibrium of the cell and to carry on various chemical processes in which energy is absorbed. In the higher plants some of the energy is also used in mechanical work.

Aerobic Respiration.—As has already been stated absorption of oxygen and the production of carbon dioxide are characteristic of the majority of plants as they are of animals. The carbon dioxide is not the only product for if sugar is oxidized an equal number of molecules of carbon dioxide are formed together with a certain amount of heat. The term *aerobic* respiration is applied to this process in contrast with the one in which oxygen is not necessary, which is termed *anaerobic* respiration and is akin to fermentation. Various substances appear capable of being oxidized in respiration, sugars, fats, proteins, sulphur, ammonia, nitrites, methane, (CH_4) hydrogen, etc., but in the higher plants sugar seems to be the substance most commonly consumed. The action is an oxidation and may be expressed thus:—

$$C_6H_{12}O_6+6O_2=6CO_2+6H_2O$$

together with a release of 674,000 calories of energy.

The intensity of respiration varies enormously in different plants and different organs of the same plant. Actively growing tissues such as meristematic tissues show the most intense respiration, in some cases as in the developing spadix of arum (*see* ARACEAE) the rate is as high as in warm blooded animals and the heat generated is sufficient to raise perceptibly the temperature of the inflorescence. Developing seeds also show active respiration; poppy seeds at 16° C give out in 24 hr. 122 cc. per gram of *dry* weight. Leaves pressed together in a receptacle where heat losses are small may in the process of respiration raise the temperature so much as to bring about their death. When sugar is used in respiration the amount of carbon dioxide given out is equal to the amount of oxygen taken in; the *respiratory quotient* (CO_2/O_2) is then one. In other cases it is widely divergent from unity especially when fats or proteins are being consumed.

Effect of Conditions on Respiration.—The rate of this process is markedly affected by various external and internal conditions. Temperature is one of the most active as is to be expected, since a rise of temperature tends to accelerate chemical processes generally. The effect on respiration is very similar to that on assimilation (*see* above) and again markedly depends on the duration of exposure to higher temperatures. The respiration rate is very low round about the freezing point, but rises with increase of temperature, being very approximately doubled for a rise of temperature of 10° C. After a time, however, an injurious effect with rise of temperature sets in—no doubt an effect on the protoplasmic mechanism, since high temperatures affect colloids.

The rate of respiration is also affected by the amount of the available material. Increase in the concentration of sugar supplied tends to raise the rate, as can be shown by adding or subtracting sugar from the food supply of a fungus in culture. A reduction of the amount of oxygen in the air has not much effect on respiration until the amount is considerably reduced. On the other hand the accumulation of carbon dioxide—a product of respiration—has a definitely depressant effect on the rate of both aerobic and anaerobic respiration.

Anaerobic Respiration and Fermentation.—Green plants which normally show aerobic respiration are still able to give out carbon dioxide when kept in an atmosphere free from oxygen; at the same time alcohol is produced in small quantities indirectly showing kinship between fermentation and this type of respiration. The alcoholic respiration of yeast has been the subject of much investigation and is known to be associated with an enzyme-zymase, and the production of a compound of sugar and phosphoric acid (known as hexosephosphate) and an enzyme which acts on this compound. (*See* FERMENTATION.) The work of Neuberg and his collaborators indicates that pyruvic acid is an intermediate product between sugar and alcohol.

Mechanism of Respiration.—The peculiarity of respiration as a chemical process lies in the fact that the plant (and animal) is able to oxidize at quite ordinary temperatures such a substance as sugar, which in the laboratory can only be burnt at high temperatures. The question arises as to the peculiar conditions in the plant responsible for this. Oxidizing enzymes have been claimed as the key to the problem, but while these will readily oxidize certain aromatic compounds they will not act on the respiratory substances such as sugars. Wieland has brought forward an entirely different theory of physiological oxidation in which water is the real source of the oxygen used. In this view the first step in the process is the combination of the respiratory material with water, which is followed by a process of *dehydrogenation*, probably under the action of an enzyme, in which hydrogen is split off leaving the material oxidized. The hydrogen is in an active state and in ordinary aerobic respiration combines with the oxygen of the air to form water; the oxygen of the air thus acts as a *hydrogen acceptor* as it is called. In the absence of air other substances, such as methylene blue or hydroquinone, can take its place. Thus the oxidation of acetic acid to alcohol can go on without oxygen if methylene blue is present. Glucose also can give carbon dioxide at ordinary temperatures when water and some catalyst, such as palladium black, are present and some acceptor of hydrogen is available. Another theory is that of O. Warburg, who holds that respiration is essentially a surface reaction. He has shown that various substances such as oxalic acid, amino acids, and even sugars are respired in the living organism. The effect of narcotics on the "respiration" of the surface is very similar to that on the respiration of the living organism. Quastel's theory of the activation of the respiratory substances and the discovery by F. G. Hopkins of the important sulphur-containing substance glutathione must be referred to. The various theories of oxidation are discussed in the English edition of Kostychev's book on plant respiration (*see* references).

GROWTH

The term growth is generally applied to the increase in size of an organism. In unicellular organisms it applies only to the increase of the single cell; in multicellular organisms it is generally associated with the formation of new cells as well as with the increase in size of cells already existing. In the growth of the cell we may find an increase in all the cell constituents, cell-wall, protoplasm, etc., though frequently an increase in volume is brought about by the enlargement of the volume of the cell without any increase of protoplasm. Of the manner of growth of protoplasm we know very little. Bacteria (which are unicellular and consist of little else than a mass of protoplasm) when placed under the more favourable conditions of temperature and food supply will multiply so rapidly that each cell divides into two new ones every 20 minutes. The protoplasm thus grows at such a rate that its mass becomes multiplied *eight times every hour.* This shows that the production of protoplasm from non-living material may go on at an astonishing rate, but of the details of this production we are quite ignorant. In cells invested with a cell wall the growth of the latter is due to the activity of the protoplasm. The new wall which divides the parent-cell into two new ones is formed across the nuclear spindle. (*See* above, *Cytology.*) There has been considerable dispute as to the method of thickening of a wall already formed, whether it is by the addition of new layers, *i.e.*, apposition, or by the intercalation of new particles of cell wall material among the old—the so-called *intussusception.* It is probable that the first process is the more common but that both occur.

Effect of External Conditions on Growth.—It is found that on the whole light has a retarding effect on growth. When illuminated the actual length attained by the organ and the rate of growth are both less than in the dark. Dicotyledonous plants grown in the dark have generally much elongated stems and also small leaves but the actual amount of light required to prevent the *etiolated* condition is very small. Light is of course indirectly necessary for the growth of the green plant, as without it the leaves are unable to build up the food material. *Temperature* is the factor which has the most marked effect on the rate of growth, as is to be expected since the temperature so largely controls the rate of the processes on which growth depends. There is a *minimum* temperature below which the growth of the plant or organ does not occur at all, a *maximum* above which the growth stops as a result of injury to the plant, and an *optimum* temperature, the one at which the rate is greatest. These, however, are not absolute terms for, as with all effects of temperature, the degree of temperature cannot be separated from its duration. This is so particularly in relation to higher temperatures which may be injurious only when the duration is prolonged. In the case of the roots of the cress plant, which have been closely investigated, the minimum is found about freezing point, 0° C; the optimum, however, was found to vary with the duration of the exposure. If the roots were tested by means of an exposure of 3½ hours to various temperatures, the optimum was at 30° C; with an exposure of 7 hr. at 29° C, while with an exposure of 14 hr. the optimum was pushed back to 27° C. The maximum also was found to fluctuate in a similar manner being higher with shorter times of exposure. Both light and temperature have also a *formative* effect on the plant in that these factors may affect the shape of plant organs; plants grown at high temperatures in weak lights are noticeably different in appearance from plants grown at a lower temperature and a higher light intensity. The formative effects of chemical substances is also often marked at least in the case of the lower plants. Another external condition necessary for the growth of most plants is a supply of oxygen.

Periodicity of Growth.—Organs of limited growth usually show what is called a "grand period of growth," the rate of growth being at first slow then gradually increasing to a maximum and then slowing down again to zero. This may be illustrated by a zone on the main root of a bean seedling which in *successive days* showed the following increases, the results being expressed in millimetres, 1·8, 3·7, 17·5, 16·5, 15·5, 14·5, 7·0, 0·0. If we express the total length of the root section graphically we have an S shaped curve; the organ or plant body starts as a small structure, grows at first slowly and then with increasing rapidity, and then the rate of growth begins to slow down and finally stops.

Correlation of Growth.—One of the most striking phenomena in the growth of the plant body is the correlation of growth. The thickness of the trunk is related to the size of the branches which it bears, and the size of the root-system is correlated with that of the shoot-system. A good example of correlation is seen in the bending up in a side-shoot to replace the loss of the top of the main stem in the tree trunk of a conifer. It has been known for some time that in the animal body hormones (chemical messengers) are produced by certain glands and that these hormones circulating about the body may control growth and other processes. It has of recent years been demonstrated that the plant possesses growth-promoting substances which can diffuse through the plant and so control growth at some distance from the point of production of the substances.

IRRITABILITY

The term irritability is often applied to the visible reactions which the plant makes to its environment. The particular action of the environment is known as the *stimulus*, and irritable responses as responses to a stimulus. The stimulus may, for example, be some change in the intensity of light or temperature or gravity or electricity. Some stimuli are necessary for the normal growth of the plant such as a suitable degree of temperature, light, etc.; without such conditions acting more or less continually on the plant body as a whole the organism would not be in a state to react to stimuli. The term stimulus is to a large extent a term serving as a cloak for our ignorance. We do not speak of the stimulus of light causing assimilation because we have some physio-chemical picture of this process. When a shoot turns in response to unilateral light we speak of the light as a stimulus, largely because we are unable to picture the course of events which cause difference of illumination to bring about curvations of the shoot or root. Stimuli have, however, usually one point in common that the stimulus does not itself supply the energy employed in the response to the stimulus, but the energy used in the response comes from a store pre-existing in the plant. The stimulus seems thus to be a releasing mechanism, in which the amount of energy employed has no relation to the energy released. The firing of a gun is a good example where the energy used in pulling the trigger has no relation at all to the amount of energy released in the explosion; irritable mechanisms of this kind are therefore sometimes called *trigger mechanisms*.

GEOTROPISM

It is well known that the plant body takes up a definite position in space. The main stem of a tree usually stands quite vertically and its branches stand out more or less horizontally. The main or top root also grows vertically downwards and the rootlets at various angles. It is well known also that if a seedling is placed with its stem and its root horizontal the stem proceeds to curve upwards and the root downwards.

Geotropic Response.—This response is known as a geotropic response, that of the stem being *negatively geotropic* and the root *positively geotropic*. We note that the curvature is usually confined to the tips of the organs, *i.e.*, to the growing points of the stem and the root. That the curvature is due to the action of gravity was shown as long ago as 1806 by Knight, the English experimenter. He fixed a number of seedlings in different positions on the edge of a wheel rotating in a vertical plane, that is, on a horizontal axis. The wheel was rotated at a considerable speed so that at its edge there was considerable centrifugal force. The result he observed was that the roots, in whatever direction they had started growing, soon grew outwards at right angles to the direction of the axis. The stems, however, grew in the opposite direction to that in which the centrifugal force was acting and they soon all met in the centre of the wheel. This experiment shows that plants do not distinguish between gravity and centrifugal force, and that the root grows in the direction of the force while the stem grows in the opposite direction. About 70 years later Sachs invented his *klinostat*, an apparatus by which plants are rotated on a disc in a vertical plane, but the speed of rotation is very slow, once in 10–20 minutes. As a result centrifugal force is negligible but the one-sided action of gravity is abolished as every side of the organ in turn faces downwards; the effect of gravity is not annulled but the curving (*tropistic*) effect is abolished. It is evident that the curvature results from the difference in the elongation of the two sides.

Geotropic Curvature is not confined to plant organs which are still in active growth. It may occur in organs which have normally ceased to grow as in the case of the stems of grasses. If a short piece of wheat or barley stem is placed in a horizontal position, the base of the node, to the growth of which the elongation of the node is mainly due, will start into growth again as a result of the stimulus of gravity and the stem turns upward. That such curvature is not a simple weight effect on the plant is shown by the *upward* curvature of the stem, and by the fact that the root often will grow downwards into mercury although in such a dense fluid the root tends to be forced upwards.

Reaction and Presentation Time.—As we are dealing with a stimulus we should expect the effect to be related to the duration, intensity and direction of the force; this we find to be the case. When a stem or root is laid horizontal the time taken for the organ to show a *visible* curvature is 10 to 20 minutes, according to the sensitiveness of the object and the external conditions, such as the temperature. This period is known as the *reaction time*. It is found that this length of time is not necessary to produce a curvature. If after a much shorter time the plant is removed from the horizontal position and placed on a klinostat, the curvature follows later. The minimum time to which the plant must be exposed to the gravitational stimulus in order to show later a curvature is known as the *presentation time*. This is much shorter than the reaction time and varies from as short a period as 2 min. for the inflorescence stalk of the plantain and the hypocotyl of the sunflower, to 25 minutes for some other plants. There is naturally a marked difference in the presentation times exhibited by individuals of the same species. In the oat shoot, for example, the mean time was 32 minutes, but some reacted in less than 14 minutes, while others required more than 49 minutes. It is found that the stimulation applied during the presentation time need not be given all at once. A series of short exposures, each less than the presentation time, may by *summation* become effective. If the pauses between stimulation are only five times as large as the periods of stimulation the presentation time is not lengthened by the intermittent nature of the treatment. Thus, if the normal presentation time of a shoot is 10 minutes, it will react if placed horizontal for five successive 2 minute periods, with a period of 10 minutes in the vertical position in between. If, however, the period between one stimulation and the next is 20 minutes, then more than 5 of the two-minute periods will be required. The effect of the stimulation thus slowly weakens during the pauses.

The presentation time and reaction time are naturally affected by the intensity of the applied stimulus. We cannot alter the effect of gravity, but we can use instead a centrifugal force which can be increased at will and to which, as has been shown above, plants respond as to gravity. The table below gives the intensity of the centrifugal force measured in terms of gravity (G), the presentation time, and the products of the time by the intensity.

Intensity	Presentation time	Product
46 G	7 secs.	322
24 ,,	12 ,,	287
4·84 ,,	60 ,,	290
0·76 ,,	415 ,,	315
0·14 ,,	2·230 ,,	322
0·04 ,,	7·800 ,,	312

We see from the third column that the geotropic reaction obeys what is called the *product law*—the time of stimulation is inversely proportional to the intensity of the stimulus, so that the product of the two is constant. This product law is also clearly shown when the root or stem is placed at various angles with the horizontal. The horizontal position is found to give the most intense stimulus, the intensity being proportional to the *sine* of the angle with the vertical at which the organ is placed.

PHOTOTROPISM

The fact that plants growing near a window will bend their shoots towards the light is familiar to everyone. This reaction is known as *phototropism,* which means a turning towards light; the term has replaced *heliotropism,* which means a turning towards the sun, since the reaction is shown in relation to almost any light. As in the case of geotropism there are two types of response, *positive* and *negative,* where the turning is towards or away from the source of light respectively. The first is found strongly marked in most shoots of the higher plants and is also found in a few roots. The positive phototropism of most roots is to be expected, since without some such response the light needs of the plant could hardly be satisfied. It is also to be noted that with the ordinary diffuse light of the sun the phototropic reaction is much more powerful than the geotropic. A seedling developing from a seed underneath a stone in a position to which light reaches, will not, under the influence of gravity, push its shoot fruitlessly against the stone above, but will show a phototropic curvature and so reach the light. Negative phototropism is found in some underground roots but markedly in the aerial roots found in many orchids. There are also plant organs which tend to set themselves at right angles to the direction of the incident light; these show *transverse* phototropism. The phototropic reaction is usually a growth reaction like the geotropic one. The side which becomes convex grows faster than the normal, and the concave side less fast. Also, as in the case of geotropism, unilateral light may cause a curvature in a mature organ by starting growth in length afresh. All light curvatures are, however, not due to growth changes but in the case of some leaves to the turgor changes of special cells.

Phototropism and the Product Law.—As with geotropism we find that the product law holds; the effect depends on the amount of light received, *i.e.*, on the product of the intensity of light multiplied by the time of illumination. The time required with different intensities of light to start a reaction, *i.e.*, the *presentation time,* is given below for the coleoptile (the seedling sheathing leaf) of the oat:—

Presentation time	Intensity (metre-candles)	Product
6 (hours)	0·00085	18·6
1	0·00477	17·2
4 min.	0·0898	21·6
4 (seconds)	5·46	21·8
$^1/_{100}$ (second)	1,902	19·0

It is seen that the product varies about the number 20, which means that the oat coleoptile will respond to 20 metre-candle-seconds. The principle of summation is also found with phototropism; stimuli too weak to cause a reaction will act if repeated. The intensity of the light required to produce an effect for a given time is found to vary with the colour, in other words, with the wave-length. It is found that *visible* light of all wave lengths will act, but the violet light is the most effective.

Conduction of Stimulus.—Charles Darwin showed as long ago as 1881 that the light stimulus might be perceived at one place and the curvature result at quite another place, showing that the stimulus was conducted. This is well seen in certain grass seedlings (such as those of *Setaria*), where the apical cotyledon soon stops growing, while the hypocotyl below continues to elongate for some time. Illumination of one side of the *cotyledon alone* will bring about a marked curvature of the hypocotyl below. In the same way unilateral illumination of the *tip* of the coleoptile of the cereal seedling, such as oat, will cause a curvation of the *lower* part. In relation to the conduction of the phototropic stimulus in this plant a very surprising result was obtained by Boysen-Jensen in 1913. He found that if the tip of the coleoptile be cut off and stuck in again with a thin layer of gelatine and the tip be then exposed to one-sided light a curvature will ensue in the darkened lower region. Later this was shown to be true for other grasses and also for the conduction of a stimulus due to injury. Snow in 1923 was able to show that the same held for the geotropic response of bean roots. If the tip is cut off and is fixed on again with gelatine the roots curve when placed horizontal. This suggests something which can pass a layer of gelatine, *i.e.*, very definitely a soluble growth-promoting substance which differs from the illuminated tip and causes the curvature. It has also been found that the slowing of the growth of a vertical coleoptile caused by decapitation can be largely removed by replacing the coleoptile in position. Such observations as these have led to a large amount of work, particularly in Holland and Germany. The most striking of the results obtained has been that of F. Went (1927), who has shown that by placing cut off illuminated coleoptile tips on small blocks of agar (a gelatine-like material obtained from seaweed) the growth-promoting substance diffuses into the agar. Blocks of this agar when placed on the cut surface of the coleoptile are able to cause curvatures.

Nature of Phototropic Reaction.—The earlier view of the positive response of stems to unilateral light was that the side towards the light being more highly illuminated had its growth rate reduced more than did the other side, with the result that the stem bent towards the source of light. Later, however, when the negative response of other plant organs was observed, and the response of transparent structures like root hairs and fungal hyphae, the view was widely held that the plant responded to the *direction* of the incident light. A. H. Blaauw was the first to return to the simpler theory; he showed that simple unicellular structures like the sporangiophone of *Phycomyces* and the complex hypocotyl of the sunflower exhibited a complicated but definite "light-growth reaction" when equally illuminated all round, the rate of growth being increased in *Phycomyces* and reduced in the sunflower. Light *apart from direction* has thus an accelerating effect in the one case and a retarding effect in the other. The turning of the hypocotyl of the sunflower towards the light is easily explicable as the side towards the light would be more illuminated and so grow more slowly. In *Phycomyces*, however, a negative phototropism might be expected, since the "light-growth reaction" is one of retardation, but in fact the curvature is towards the light. Blaauw, however, pointed out that the glass-like cylindrical structure of the sporangiophore acts like a lens and focuses the light on the further side, which is thus more intensely illuminated than the nearer. As a result of his work Blaauw put forward the view that in general the phototropic reaction is simply a growth response to differences of light intensity on the two sides of the organ.

The chemotactic movements of antherozoids and bacteria and the chemotropic movements of roots cannot here be dealt with, but a few words must be said on the so-called *nastic* movements of plant organs. These are movements which may be called out by a change in external conditions, but, as already stated, the nature of the movement is not determined by the stimulus from outside. The perianth leaves of the tulip exhibit a *thermonastic* movement, for when the temperature is raised these leaves open as a result of the greater growth of the upper sides. Many flowers show *nyctinastic* movements, opening and closing in response to changes of light intensity. Similar movements, the so-called *sleep movements,* are also known in leaves, especially in the leaves of Leguminosae.

Photoperiodism.—A very interesting reaction to light, which is in no sense a phototropic response, has been discovered of late years. It is a familiar fact that at least in temperate climates many plants flower only at certain periods of the year; there are so-called spring flowers, autumn flowers and plants which flower in the summer. This marked seasonal effect must be due to some varying external condition or set of conditions. It has often been supposed that temperature plays a large part in the development of flowers, and a certain degree of warmth is essential for growth, yet altering the temperature alone will not markedly alter a plant's flowering period. Asters and chrysanthemums cannot be made to flower in summer by lowering the temperature, nor irises in winter by putting them in a greenhouse.

Apart from temperature there is one regular cyclical change associated with the march of the seasons and that is the change in length of the day and night, the day in the latitude of London varying from 16½ hours in June to a little under eight hours in December. It was shown by Garner and Allard that in the case of many plants it is the length of the day which is the decisive factor in fixing the season of flowering. The discovery was made in the United States, where the behaviour of a valuable variety of tobacco, known as Maryland Mammoth, was being studied. It had been found impossible to obtain seeds from this variety since it went on growing steadily through the season, sometimes reaching a height of 12 ft., being eventually cut down by frost before it had formed flowers. One autumn a specimen was transplanted to a greenhouse, where it promptly flowered and set seed. This was at first thought to be an effect of temperature, but further investigation showed that it was impossible to cause the plants to flower in summer. It was soon found that the *dominating factor was length of day;* if growth conditions were favourable it would flower in the short days of late autumn or winter but not in the long days of summer. By artificially shortening the day to 12 hours, by placing the Maryland Mammoth plants in the dark during some of the daylight hours, flowering could be brought about at any time of the year. Following up this discovery Garner and Allard investigated at Washington the behaviour of a large number of plants. These were grown in pots which were borne upon light trucks running on lines so that the pots could be run in and out of sheds and thus be illuminated for various fractions of the daylight period. Many plants, such as the tobacco variety mentioned above, soya beans, asters, chrysanthemums, poinsettia, were found to be "short day" plants, and would only flower when the period of daylight was reduced to 12 hours or less. If the time of illumination is suitably adjusted the plants will flower and fruit when they are quite diminutive, while other individuals exposed to full daylight grow to a large size without any trace of flower production. Other plants such as grasses have been shown to be "long day" plants, which require a long daily period of illumination for the initiation of flowering.

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PATHOLOGY OF PLANTS

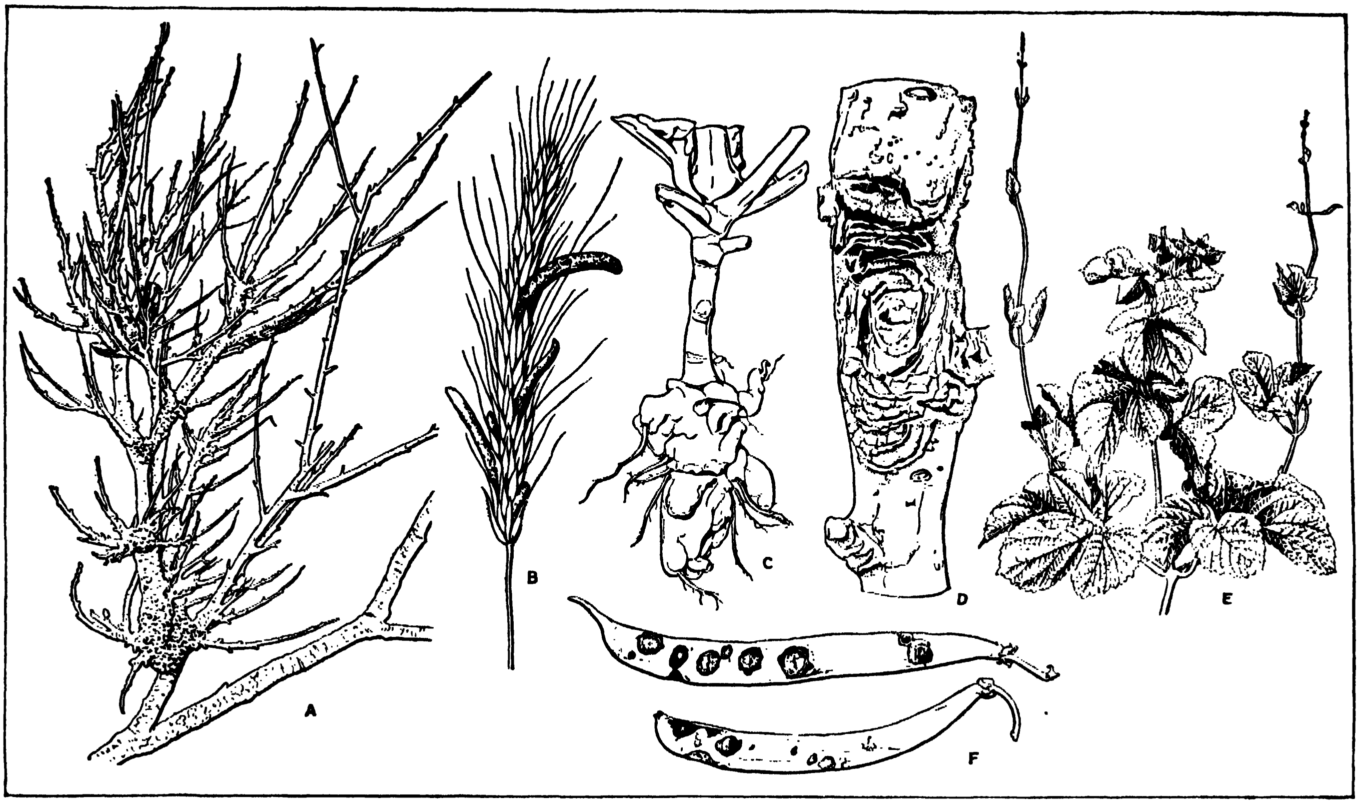
Plant pathology (or Phytopathology) is that branch of biological science which treats of the diseases of plants. While there can be no doubt that diseases of plants, and in particular of cultivated plants, have manifested themselves from time immemorial, it is only within comparatively recent years that their study has been taken up in an organized and scientific manner. The application of the scientific method generally to the study of practical agricultural problems is a development scarcely older than the 19th century.

Historical.—In view of the devastating effects of plant disease, especially when the particular plant attacked is of primary importance as food for mankind or his domestic animals, it is not surprising to find that references to epidemics of disease are not uncommon in historical writings, even of remote times. The earliest records are to be found in the Old Testament (*e.g.,* Deut. xxviii., 22, 1 Kings viii., 37) under such terms as "blasting" and "mildew." The precise nature of the diseases referred to cannot now be determined but there is little doubt that some of the epidemic diseases of cereals, such as rust or mildew, are indicated. The ravages of insects are frequently noted, such as for instance plagues of locusts, caterpillars and canker-worms.

In Greek literature we find references to plant diseases in the writings of Aristotle, and more particularly in those of his pupil Theophrastus, the father of botany. The latter describes diseases of a number of cultivated crops, such as various legumes, cereals, fig, olive, etc., and observes that varieties of the same crop may show different degrees of resistance to disease. This is probably the first mention of the idea of "resistant varieties" which figures so largely in present day writings on the subject. Among Roman writers the younger Pliny, who flourished in the 1st century of our era, devotes some attention to the subject and makes a number of well-founded observations regarding the incidence of certain plant diseases.

The middle ages were for plant pathology, as for all other sciences, dark ages and we have to come down to the Renaissance, with its general quickening of interest in all intellectual pursuits, to find evidence of further progress. The 17th and 18th centuries witnessed considerable activity in the study of plant diseases. The new studies proceeded in the main from two different directions. The practical gardener or agriculturalist was chiefly concerned in describing the various diseases to which his crops were subject and in attempting to evolve methods of treatment. On the other hand, the student of human pathology was interested in the diseases of plants from the possible analogies to his own problems which such a study might offer. The whole science of botany had in the old days a distinct medical bias. It is not surprising, therefore, that the study of plant diseases has been to a large extent modelled upon the older science of human pathology, the terminology of which has been freely borrowed.

The elucidation of the real nature of plant disease, from the point of view of the causal agent, is mainly dependent upon the perfection of the microscope. But even the extended powers of observation which the use of that instrument brought to bear on the subject did not at once lead to a correct appreciation of the true nature of plant disease. Various structures were observed and accurately figured in detail as being associated with the diseased parts, but they were interpreted as portions of the plant which had become changed by the disease and not as belonging to a distinct organism which was responsible for the disease. The first incontestible proof that a specific plant disease was due to the invasion of the tissues of the plant by a definite parasitic organism was furnished by the German scientist, De Bary, whose pioneer researches prepared the way for a host of other workers, at first chiefly in Germany, and later in all civilized countries. The 20th century has witnessed an extraordinary activity in the study of problems of plant disease, most strikingly, perhaps, in the U.S.A. The economic importance of the subject, as a branch of scientific agriculture, has become increasingly recognized and the prosecution of plant disease researches is being more and more taken up by Government departments in all countries possessing a progressive agriculture.



FROM (A, B, C, D) DUGGAR, "FUNGOUS DISEASES OF PLANTS" (GINN & CO.), (E) SALMON & WARE IN JOURNAL OF MINISTRY OF AGRICULTURE (H.M. STATIONERY OFFICE), (F) WILTSHIRE IN "STUDIES ON THE APPLE CANKER"

FIG. 1.—TYPES OF PLANT DISEASES
A. Abnormal development of buds on branch of cherry giving rise to "witches' broom." B. Ergot of rye, showing replacement of grain by a fungal structure (Sclerotium). C. Finger-and-toe or club root disease of cabbage. D. Canker of apple tree. E. Spike disease of hop (Central branch diseased, lateral climbing branches healthy). F. Spotting of fruit disease "Anthracnose" of bean

Definition and Scope.—While it is true that the distinction between a healthy and a diseased plant is often perfectly obvious, it is not easy to frame a definition of the diseased condition which will meet all cases. The border line between health and disease is not always sharply marked. It will be shown below that the majority of plant diseases result from the invasion of the plant tissues by a definite organism, the *parasite*. Nevertheless, the presence of a parasite does not always necessarily mean disease in the common acceptation of the term. For example, the root-nodules of leguminous plants (pea, bean, clover, etc.) are produced by the attack of an organism—a bacterium—and far from producing damage, the presence of the bacterium is essential to the proper development of the plant. The important part played by certain fungi in the germination and subsequent growth of many plants, such as orchids and heaths, is a further illustration. The living together of two organisms does not necessarily produce injury to either partner, in which case one speaks of a *symbiotic* relationship. Every gradation may be traced from the purely symbiotic type, in which the two partners are benefited or not obviously injured, to the distinctly parasitic type in which one partner thrives at the expense and to the detriment of the other. In fact both types of relationship may be shown between the same two partners—that is, a symbiotic or harmonious relationship is at first set up, but by and by one of the partners suppresses the other and the relationship becomes one of parasitism. There is thus a gradual transition from a condition of health to one of disease.

So far reference has only been made to the diseases of parasitic nature. Over and above these there is a class of diseases in which no parasite is present at all, viz., the so-called *physiological diseases*. The existence of the latter increases the difficulty of defining disease in terms of the causal agent.

Perhaps the most adequate definition is obtainable by considering the normal development of a plant. Over a certain range of conditions, which one reckons as normal, a particular species of plant develops in a certain way—*e.g.*, has a certain appearance, reaches a certain size, and so on—all of which are the reflection of a normal physiology or functioning of the plant. If now a particular individual diverges from the normal and if the abnormality impairs the functioning and more especially imperils the life of the plant, that plant may be considered as being diseased.

From the purely practical or economic point of view, a satisfactory definition of disease presents no great difficulties. Any given crop is grown in the expectation of a certain yield, both as regards quality and quantity. Disease in its economic aspects may therefore be defined as a condition of the crop in consequence of which it fails to give a satisfactory yield.

General Classification.—Diseases, whether of plants or animals, may be classified on the basis of the symptoms produced or of the causal agent concerned. For reasons given more fully below, the latter system of classification is more generally adopted in connection with plant diseases, and it is convenient to give at this point a general classification along such lines in order to limit the scope of the present article. Classified on the basis of the causal agency, plant diseases are as follows:—

(1) Diseases due to the non-living environment.

(2) Diseases due to so-called *internal* causes.

(3) Diseases due to living agencies, which may be plants or animals.

The first two groups constitute the *physiological* diseases. In group (1) the disease symptoms can be related to certain physical or chemical features of the environment. In group (2) no such association has yet been demonstrated, nor has it been possible to explain the symptoms as being due to the presence of a parasite. The second group is thus defined on purely negative characters, and is in fact a kind of limbo into which are put all diseases the cause of which is still obscure. Some of these may prove, with advancing knowledge, to be referable to either of the other groups.

The members of the third group constitute the *parasitic* diseases. The plant, technically termed the *host*, is attacked by another organism called the *parasite*. The animal parasite may be various —mammal, bird, snail, insect, eelworm, etc. The attack of a crop by such an animal as a rabbit is not usually described as a disease, though there is no difference in kind between such attack and that produced by mites or greenflies. Economically the most important diseases of animal origin are those produced by insects, and these constitute in the main the province of the entomologist. (*See* ENTOMOLOGY: *Economic.*)

Plant parasites may be bacteria, algae, fungi (including slime-fungi) or higher plants. Plant diseases of bacterial origin were at one time believed not to exist, on account of the supposed fact that the acidity of plant juices is inimical to bacterial growth. Many bacterial diseases of plants are now known, some of great economic importance. The recorded cases of parasitism due to algae are few and unimportant. Diseases caused by higher plants, some of which will be cited later, are on the whole of greater scientific interest than of economic importance. The fungi (*q.v.*) are by far the most important group of disease-producing organisms, so far as plants are concerned.

Broadly speaking, therefore, the plant pathologist is by training either an entomologist or a mycologist. As far as diseases of parasitic type are concerned, only those caused by plants, and therefore chiefly of fungal origin, will be dealt with in the present article. At the same time it is important to note that the two aspects of the study of plant disease, the entomological and the mycological, cannot in practice always be separated.

Symptoms of Disease.—The study of symptoms is the first step in the examination of a disease problem. By symptoms one means the total of the modifications shown in the plant as the result of disease. In the majority of plant diseases of parasitic type the true symptoms are accompanied at one stage or other of the disease by certain appearances such as the fructifications of the parasite.

A very important difference between the typical plant disease and the typical animal disease is as regards the definiteness of the symptoms shown. In animals and especially in man disease symptoms are usually very characteristic, so that it is often possible to identify (or *diagnose*) a particular disease from a study of the symptoms alone. With plants this is not generally possible. Disease symptoms in the latter are much more generalized, *i.e.*, the same or approximately the same symptoms can be produced by a great variety of causes. Wilting of the foliage, for example, is a symptom of disease in plants and its cause may be most varied—damage to the roots by fungal or insect attack, damage to the stem, presence of injurious salts in the soil, scarcity of water, and so on. Hence it follows that while a study of the symptoms may give valuable indications of the nature of a particular plant disease, it is in general necessary to discover the cause or *aetiology* of the disease before the latter can be definitely identified. Determination of the causal agent may be difficult and usually involves considerable expense of labour and time.

While the main symptoms of plant disease are of a rather generalized nature, a number of different types may be distinguished. The more important of these are given in the following list:

(*a*) *Change of colour,* such as paleness, silvering, reddening, blackening of leaves. The change of colour may be shown over the leaf or even over the whole plant, or it may be limited to spots, streaks or patterns, such as the well-known "mosaic" appearance.

(*b*) *General wilting* of the shoot, as when the plant suffers from drought, or from "damping off" disease, or from the effects of a parasite which destroys the roots or is present in the water-conducting system.

(*c*) *Premature shedding* of leaves, blossoms, fruits, etc.

(*d*) *Abnormal retention* of leaves, which is especially well shown in certain diseases of deciduous trees. The autumnal shedding of leaves is a vital or physiological process, due to the action of a definite *absciss* or cutting-off layer at the base of the leaf. If this layer is prevented from functioning, as for example by the killing action of a parasite which has invaded it, the leaves cannot be shed in the normal way.

(*e*) *Dwarfing or stunting,* which may be general to the whole plant or may only be shown in particular organs.

(*f*) *Abnormal enlargement or multiplication* of parts (*hypertrophy*) resulting in the formation of such structures as galls, tumours, knots, warts, etc. (fig. 1). Hypertrophy is generally accompanied by distortion or malformation as in the rolling or puckering of leaves and the twisting of shoots. Frequently it takes the form of an abnormal development of buds, the majority of which would normally have remained dormant. The structures called "witches' brooms" (fig. 1) which are common on certain trees (*e.g.*, willow, birch) are produced in this way.

(*g*) *Replacement* of one organ by another, as for example the change of petals into foliage leaves. Some changes of this type, though properly speaking malformations, may be economically desirable and are therefore not considered as diseases. An example is the "doubleness" of some flowers.

(*h*) *Change of habit of growth, e.g.,* from the prostrate to the erect, from the climbing to the non-climbing type of growth (fig. 1).

(*i*) *Change in the periodicity relationships* of the plant, as for example the premature flowering ("bolting") of a biennial plant in its first year of growth, or the opening of foliage or floral buds at the wrong time of year.

(*j*) *Replacement* of parts of the plant by structures belonging to the parasite, such as the conversion of the rye grain into the resting organ (*sclerotium*) of the Ergot fungus (fig. 1). "Mummification" of certain fruits is another example of this type.

(*k*) More or less rapid *killing* (*necrosis*) of the plant or parts of it. Killing is often accompanied by more or less pronounced rotting, as in the decay of fruits, buds, etc. (fig. 1). Localized killing of leaves results in the formation of dead spots. The killed tissue may remain as such or may dry up and fall out, thereby producing a "shot-hole" effect.

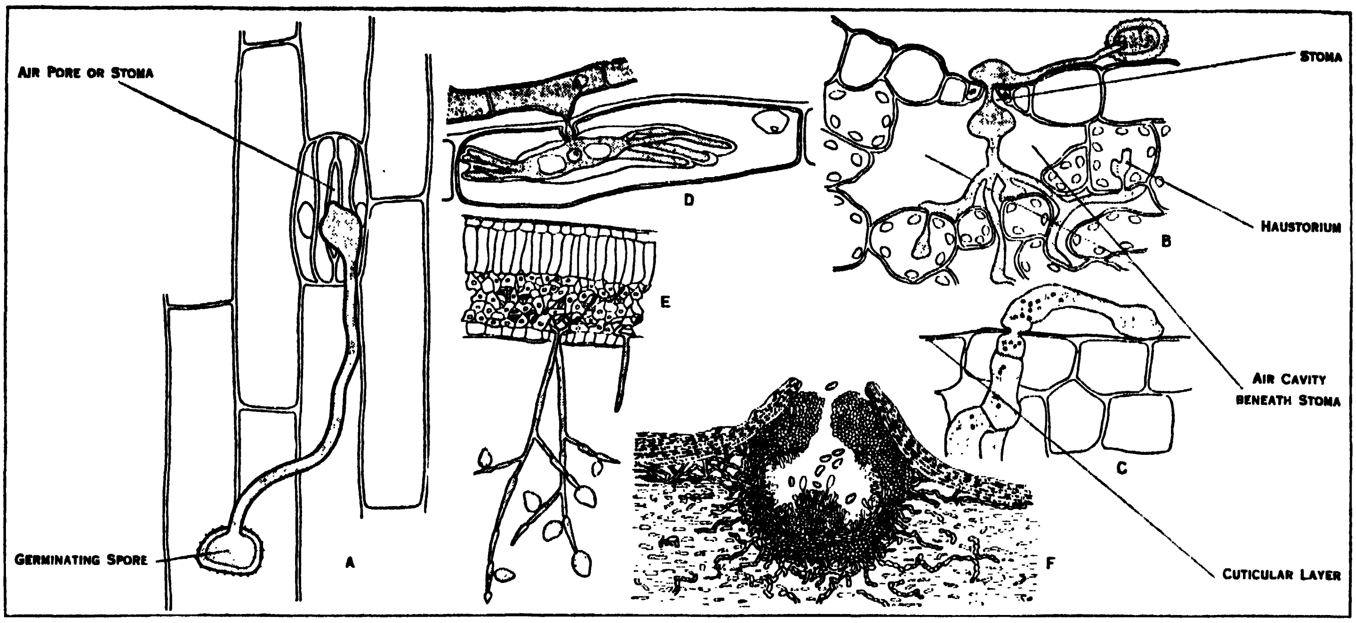
(*l*) Formation of *deep-seated wounds* or *cankers* (fig. 1). In a canker, the parasite slowly eats into the plant tissue, the part invaded being killed and to a large extent disappearing. Associated with this type of wound there is usually a certain amount of hypertrophy of the tissue which still remains alive round the margin of the invaded part.

(*m*) Various kinds of *exudations,* as in the gumming of plum trees or the abnormal flow of resin in certain conifers.

METHOD OF STUDYING PLANT DISEASE

Though the investigation of a plant disease is a matter for the specialist, a short account of the methods adopted will serve to indicate the type of problems encountered. The parasitic type of disease is in practice the one most frequently met with, and therefore in actual study it is usually assumed in the first instance that the disease under investigation is of parasitic origin.

Identification of the Parasite.—The first problem which arises is the determination of the nature of the parasite (assuming that such is actually present). The tissues of the plant which show the symptoms of disease are examined, after suitable preparation, under the microscope and if the disease is actually due to a parasite it is usually not difficult to demonstrate its presence. Definite indications of its nature and identity may also be obtained at this stage. In a number of cases, the parts of the plant which show the symptoms of disease may appear to contain no parasite, even though further study may confirm that the particular disease is of truly parasitic nature. Thus the parasite may be so small as to be beyond the range of microscopic vision (*see* Virus diseases, below), or, as occasionally happens, the parasite is located elsewhere but is able to produce symptoms in parts of the plant remote from it. The mere presence of a fungus or bacterium within the diseased part (or *lesion*) is not, however, a certain indication that the disease is caused in that way. Direct proof can only be obtained by inoculating healthy plants of the species showing the disease with the organism in question and observing whether the disease is thereby produced. The details of the procedure involved in the carrying out of such artificial inoculations will vary much in different cases. In general it is necessary, as a first step, to prepare "pure cultures" of the organism, that is, to grow the latter in such a way that no other organism is present. These pure or unmixed cultures of the organism are then tested separately by inoculations on the host plant, and by this means evidence is obtained as to which is the active parasite concerned. The active parasite being isolated and its pathogenicity



FROM (A) PHILOSOPHICAL TRANSACTIONS, (B, C) ANNALS OF BOTANY, (D) BOTANICAL GAZETTE (UNIVERSITY OF CHICAGO PRESS), (E, F) DUGGAR, "FUNGOUS DISEASES OF PLANTS" (GINN & CO.)

FIG. 2.—THE FINER STRUCTURE OF SOME PARASITIC FUNGI (MAGNIFIED)

A. Surface view of plant leaf, showing rust spore germinating, B. Section of leaf showing entrance of rust fungus through a stoma, C. Penetration of cuticular layer of plant by fungus, D. Haustorium or abortive process of mildew within plant cell, E. Fructification of potato blight fungus which bears egg-shaped spores on its branches, F. Fructification of Black Rot fungus embedded in the tissue of an apple, rupturing outer skin of the plant

(or capacity to produce disease) proved, one is now able to identify the particular disease in terms of the parasite which is responsible for it.

Identification of the disease is of value inasmuch as it enables the investigator to correlate his work with similar work done elsewhere, and of which a record is obtainable in the scientific literature. But mere identification is not the most important part of the study. It is essential to work out the *life-history* of the fungus—*i.e.*, to know where and in what form it occurs throughout the year. The same fungus may exist in a variety of forms in different situations or at different times of the year, and it is essential to connect up the various stages. In particular it is very important to establish the manner in which the fungus passes the winter (or equivalent) season. In temperate climates, for example, a summer growing season alternates with a period of dormancy during the winter. Often it is only on the actively growing crop in summer that the disease is observable. It reappears each spring, spreads during the summer, and becomes more or less latent during winter. The considerations which arise in this connection vary much in the different cases. A few examples will illustrate this. Annual crops pass the winter season in the form of seed. Is the disease therefore carried over the winter by means of the seed, and if so is it present within the seed, or is it carried on the surface? Or does it persist in the soil, or is the new crop infected afresh from dead remains (stubble, trash, etc.) of the preceding year's crop? Or again, do various perennial plants, such as certain weeds, serve to carry the disease through the winter? With perennial crop plants such as fruit trees, there is the further possibility that the disease may overwinter in a resting form on or in the plant itself. The determination of the exact method of overwintering which obtains in any particular case is obviously of the greatest practical importance.

The further examination of a disease problem from the point of view of the parasite would take into consideration the geographical range of the latter. Plants showing the particular symptoms would be obtained from different localities and the parasites isolated and compared. Thus a general idea would be obtained of the geographical distribution of the parasite and of the range of host plants which it could parasitize.

The complete elucidation of a plant disease involves much more, however, than the determination of the existence and habits of a parasite as outlined above. The presence of the parasite is only one of the conditions essential for the appearance of a specific parasitic disease. The more important factors and the manner in which they operate will now be indicated.

Temperature.—First as regards temperature. This factor determines in large measure the rate of growth and general vigour both of parasite and host. There is a certain temperature (*minimum*) below which an organism will not grow, a *maximum* above which it will not grow, and an *optimum* at which it grows best. These three temperatures constitute the so-called *cardinal points* for the particular organism. The cardinal points for the parasite are not in general the same as for the host plant, and the cardinal points for the disease itself are not the same as those of either host or parasite. Usually the range of temperature over which disease takes place is distinctly narrower than that over which either of the two organisms concerned will grow. The optimum temperature is well known in many cases to be different for host and parasite, and thus it is clear that the possibility exists of finding a temperature at which the host plant grows well but which is unfavourable for the development of the disease. The precise relationships are somewhat complex and have been fully worked out for a limited number of diseases only, but it is possible in general terms to classify diseases into the two main types, high temperature and low temperature diseases. An example of each will show the difference. The root-rot disease of tobacco is one of the low temperature type. Susceptible varieties of tobacco when grown in infected soil are badly diseased if the temperature rules low, whereas in the same soil the disease would not occur at a higher temperature. The wilt disease of cabbage is of the high temperature type, and only occurs in seasons when the general ground temperature is high.

Water.—The water-relationships of the crop are of equal importance with those of temperature and are to be studied in terms of the amount and distribution of rainfall, the water-retaining capacity of the soil, drainage, etc. Two factors which are of great importance in the initiation of parasitic attack are the relative humidity of the air surrounding the plant and the percentage of moisture present in the soil. The parasite requires the presence of a certain amount of moisture to start its growth processes. So it will often be possible for the plant pathologist to explain the occurrence of disease at one time or place and not at another in terms of these factors. The percentage of moisture in the soil affects not only the capacity of the parasite to grow but also the growth of the roots of the plant. It may therefore also influence the capacity of the roots to resist the attacks of the parasite.

Light.—Light is also a factor which influences the susceptibility of a plant to disease. The quantity of light received by the plant determines in large measure its vigour of growth, not merely as regards the amount of new tissue formed, but also as regards the mechanical strength and to a certain extent the chemical composition of the tissues of the plant. These qualitative differences influence the degree of resistance which the plant can offer to the attack of a parasite. For example the weak, pale, rather juicy, "forced" type of growth which results when plants are grown under conditions of feeble illumination—as when plants are grown in glasshouses during winter or when they shade each other by standing too closely together—predisposes them to attack by a variety of fungi ("damping-off" diseases). On the other hand, certain fungi (*e.g.*, some of the rusts) attack their hosts with vigour only when the latter are growing under conditions of good illumination. Again, the symptoms of certain diseases (*e.g.*, some mosaics) will only appear when the plant is exposed to light of a certain range of intensity.

The three fundamental factors, temperature, humidity and light are, in the open field, to a large extent beyond control. Nevertheless, it is often possible, in agricultural practice, materially to modify their action. By suitable methods of cultivation—draining, subsoiling, ridging, manuring—the amount of soil water can be regulated. By the provision of shade trees—as is usual in many tropical cultivations—or by suitable spacing of the crop itself or by pruning, the intensity of light or humidity of the air can be adjusted so as to approximate to the needs of the plant.

Soil Factors.—Reference has been made to soil moisture as a factor of importance in connection with plant diseases. This is merely one of the many soil factors which influence plant growth and which therefore require to be considered in dealing with the liability of plants to disease. The physical texture of the soil and the presence or absence of certain chemicals are of importance mainly inasmuch as they influence soil humidity. But there are in addition a number of soil factors which act otherwise. Thus the amount of certain constituents present in the soil (*e.g.*, nitrogen, potash, phosphate) influences not only the quantity of plant growth but also, to an appreciable degree, its quality—and in particular its susceptibility to disease. The presence or absence of lime, by controlling the reaction of the soil, is in some cases the factor which determines whether a particular disease will develop or not. Soil aeration is a factor in itself, though in practice it is often difficult to separate its effects from those due to soil humidity.

Internal Factors.—So far the discussion of the factors which influence plant disease has been limited to the environment. The latter, however, merely modifies the result which is in the main conditioned by the structure and physiology of the host plant itself. These "internal" factors are more elusive than those already discussed and in their fundamental aspects are practically unmapped. A few examples of internal factors and of their manner of functioning will be given in the following section. Nevertheless, though very little is known of the underlying factors which determine immunity or susceptibility, certain phases of the problem are open to direct observation and experiment.

From the foregoing sketch it is clear that the complete investigation of a plant disease may ramify into various branches of agricultural science. The plant pathologist is thus much more than a mycologist, or student of fungi, though in practice the two names are often used as equivalent. Plant disease investigations may call for the joint work of the mycologist (or entomologist), the soil chemist, the physicist and the practical agriculturalist, and lastly—as will be shown more clearly later—the co-operation is required of the geneticist for the breeding of resistant varieties, and of the pure chemist for the preparation of chemical means of combating the disease.

NATURE OF DISEASE; PHYSIOLOGY OF PARASITISM

The discussion under this heading will be confined almost wholly to diseases of parasitic nature. The problems presented in parasitic disease are simpler inasmuch as the interactions of parasite and host plant can be studied under the microscope, and to a certain extent at least are amenable to chemical and physical analysis. For simplicity, the description will be confined to a disease of fungal origin.

The earliest phase of such a disease is the entrance of a fungal thread or *hypha* (*see* FUNGI for account of fungal structure). The fungus, usually in the form of a spore, germinates on the surface of the plant, or otherwise comes in contact with the latter. It then enters, either by naturally occurring openings (stomata, water pores) (fig. 2) on the surface or by boring directly through the skin or cuticle of the plant (fig. 2). Certain parasites, known as *wound parasites,* are only able to enter through openings or wounds which have been made by other agencies; *e.g.*, insect bites, bruises due to processes of cultivation, frost cracks, wind damage, pruning wounds, etc. Then again dispute exists as to whether the actual process of penetration is effected by purely mechanical means or by the agency of some chemical substance which softens or dissolves the cuticular layer of the plant. Once inside the plant, the fungus progresses by sending hyphae through the tissue, either between the cells (*intercellular*) or into the cells (*intracellular*). The particular relationship shown—*i.e.*, whether the hyphae are *between* or actually *in* the host cells—is more or less characteristic of individual diseases. In many cases the hyphae of the fungus ramify between the cells of the host and here and there send characteristic outgrowths (*haustoria*) into the cells themselves (fig. 2). These outgrowths are clearly the organs which enable the parasite to abstract its nutriment from the host cells.

While the fungus is progressing through the plant, the cells of the latter in the neighbourhood of the parasite, or even at some distance from it, show a number of more or less characteristic changes. The total sum of these changes, it should be noted, constitute the symptoms of the disease. The details of the changes shown vary much from one disease to another, but broadly speaking one can distinguish two main types of disease, each with a characteristic set of host changes associated with it.

Generalized Parasites.—In the first type, the fungus pours out certain chemical substances into the surrounding host cells, with markedly destructive effects to the latter. The living contents (*protoplasts*) of the cells are killed and the walls which separate the individual cells (and which form the mechanical skeleton of the living plant) are softened or partially dissolved. The destructive principle exuded by the fungus is able to diffuse out into the host tissue and thus bring about killing of the latter well ahead of the growth of the fungus. Fungi of this type are therefore not parasites in the strict sense of the term, inasmuch as they are growing all the time, not on the living plant, but on parts of it they have previously killed.

This type of parasitism is relatively simple and crude. The fungus, so to speak, is in the nature of an assassin who kills and then plunders his victim. The essential part is the killing and this merely entails that the fungus must possess the necessary battery of substances for carrying out this process. In these respects such fungi and the diseases to which they give rise stand in marked contrast to the type which will now be described.

Specialized Parasites.—In the second type of disease, there is no rapid killing or rotting effect produced by the parasite on the host cells in the neighbourhood. The cells of host plant and parasite live side by side for a considerable time with no apparent damage to the former. Indeed it frequently happens that the presence of the parasite stimulates the host cells to unusual growth and activity. Thus the cells in the neighbourhood of the parasite, some of which are actually penetrated by the food-absorbing processes of the latter, are often found on examination to be more richly supplied with food reserves than are the normal cells removed from the zone of influence. If the part of the plant affected is a leaf or other green part, the stimulating effect produced by the parasite may often be seen in the more intense green round the margin of the invaded spot than elsewhere. The stimulating action in many cases takes the form of renewed growth on the part of cells which normally would not have grown further. In this way are produced the tumours, galls, warts, witches' brooms, etc., frequently associated with diseases of this type. Such parasitism illustrates the *symbiotic* relationship to which reference has already been made. The symbiotic relationship may persist for a considerable time, but by and by injurious effects supervene, leading to more or less extensive destruction of the host tissue.

The second type of parasitism is much more subtle in nature than the first. The method of attack adopted has no resemblance to that of the assassin but savours rather of the blackmailer whose interests would not be well served by the premature death of his victim. Up to a point the interests of blackmailer and victim are identical, and if the association leads to unusual industry on the part of the latter the final harvest is all the richer. In diseases of the second type an analogous behaviour is shown. The analogy can in fact be pressed more closely still. Fungi which produce the first type of disease are, like the assassin, not selective in their action. In diseases of the second type, on the other hand, a high degree of selectivity is typically shown.

Fungi which produce this specialized type of disease show specialization in other respects. Their food requirements are of a very particular nature, and on this account it is generally impossible to cultivate them on any medium other than the living plant to which they are specialized. The symbiotic relationship is apparently necessary, and if this is not developed, no effective parasitism ensues.

As fungal attack progresses, one usually finds that the parasite makes provision for its further distribution by the development of a fruiting or sporing stage. The spores may be formed within the tissue of the parasitized plant and are disseminated only when the latter is decomposed, as for example by rotting on the surface of the soil. More generally the fructifications of the fungus are developed on or towards the outside of the plant, either emerging from the stomata or bursting through the outer skin (fig. 2). Many fungal parasites develop two kinds of spore. One of these is produced in profusion during the growing period and serves to spread the disease rapidly to new plants. This is the so-called summer spore, which is usually short-lived and germinates with great readiness when the environmental conditions are suitable. The second type of spore is usually produced later in the season. This is a resting form which typically will not germinate until after a certain interval has elapsed, and which in some cases requires exposure to winter cold before it is capable of germination. The resting spore is usually provided with a thick protective wall, and is capable of enduring long exposure to atmospheric conditions. Its function is to carry the fungus over the winter.

Immunity.—The preceding sketch of the progress of a successful parasitic attack would be incomplete without some reference to those features of the plant which confer resistance or immunity to disease. These are the "internal" (as apart from environmental) factors to which reference was made above. It was also pointed out that immunity to certain highly specialized fungi was really due to over-susceptibility.

It may be noted in the first instance that a plant may be immune in the practical sense for the reason that it merely *escapes* disease. Internally it may be just as susceptible as other plants which become badly diseased. The presence of water-drops on the surface, which enable germination of the fungal spores, is a necessary antecedent to attack. Many plants are enabled to escape attack on account of a property of their outer surface which prevents the adherence of water.

With fungi which penetrate the cuticle, the strength of the latter is obviously of importance, at least if the mechanical view of penetration is accepted. In many cases there is definite evidence that this factor comes into play. Thus certain fungi are only able to attack the young leaves in which a mature, fully thickened cuticle is not yet present.

When the fungus has actually entered the tissues of the plant, it must, if parasitism is to be effected, be able to live in the sap with which it comes into contact. Attempts have therefore been made to explain the susceptibility or resistance of a tissue in terms of the properties of the plant juices. Certain difficulties of a technical nature are met with in such investigations; *e.g.*, it is not certain how far an extract which is pressed out from a plant is a true representation of the cell-sap originally present in the cells. Up to the present it has been possible only in a few cases to correlate the resistance of the host tissue to fungal attack with the anti-fungal properties of the plant juice.

The method by which the "killing" type of fungus breaks down the resistance of the host tissue is by excreting certain enzymes which partially dissolve the cell walls and kill the protoplast. These ferments are highly specific in action; *i.e.*, they are active on some tissues and not on others. The main factor in this connection seems to be the chemical composition of the cell walls.

So far we have dealt with possible chemical measures of defence. Many plants adopt a mechanical means of defence by laying down a protective layer of cork in advance of the parasite. The corking-over of an exposed or wounded surface is a common reaction of plants, and the same often takes place in response to the wound caused by a parasite. One or more layers of corky cells are formed somewhere along the line of separation between diseased and healthy tissue, and these act as a mechanical barrier to further progress. Any condition of the invaded plant which tends to accelerate this formation of cork increases the resistance to attack, and conversely. Similarly it has been shown in one case (the "silver leaf" disease of plum trees) that resistance depends on the formation, as a wound response, of a layer of hard gum which mechanically shuts off the parasite.

No reliable evidence exists as yet of any formation of antibodies such as play a fundamental part in the arrest of certain animal diseases. Here we meet with another illustration of the essential difference between plant and animal diseases.

ECONOMIC IMPORTANCE OF PLANT DISEASES

The number of known plant diseases is very great, and even if those occurring on non-economic plants are ignored, there is still a large residue. A glance at the disease lists of economic crops, such as are published from time to time by departments of agriculture and other bodies, will show as many as twenty or more diseases occurring on particular species of cultivated plants. The majority of these appear, for the present at any rate, to be of little economic importance, but one may say generally that more or less all cultivated plants are subject to two or three diseases of major importance, which at various times or places interfere seriously with their profitable cultivation. Thus in the case of the potato, one may cite four important diseases, blight, wart, common scab and virus disease, all of which afford serious problems to the grower. Of the many diseases reported on the apple, one may mention mildew, scab, canker, brown rot, bitter pit and scald as of the greatest economic importance; and so on, for other crop plants. In any one year and in a given locality, certain of these diseases may do little damage or may even appear to be absent, but over a wide area and over a period of years the aggregate loss is very great. One might forecast that the seriousness of the losses due to plant disease will tend to become greater as the gradual increase in the world's population makes it less possible for the supply of any product to outstrip the demand.

Though the farming class as a whole may in certain cases reap an advantage from the prevalence of plant disease, to the individual farmer the occurrence of disease in his crops can only bring loss. He therefore adopts certain measures with a view to protecting his crops and submits to various legislative restrictions, the object of which is to prevent or limit the spread of plant diseases. All these measures have as their ultimate result an increased cost of production of the article concerned, and this in the long run represents a loss to the community.

Epidemics.—It is, however, when plant disease comes on in epidemic form that the most striking damage is produced. The general public which is unaware of the widespread and ever-continuous frittering away of plant products as a result of disease, sees then the disease in its most concentrated form. Such epidemics have at one time or other produced enormous losses. They have profoundly influenced the economic development of certain countries, and have led frequently to acute distress and famine. The following examples will serve to illustrate these statements.

The rust diseases of cereals are present in all cereal-producing countries and the annual loss in many of them runs into millions of pounds sterling. The estimated loss from the stem-rust disease of wheat in 13 of the northern United States for the ten-year period 1915–24 is given as about 550 million dollars, half of which loss was incurred in a single "rust" year, 1916. The rust epidemic of 1891 cost Prussia about three-quarters of the whole cereal crop. Similar disasters have occurred in India, Australia, South Africa and other wheat-growing countries. It is simply the fact that wheat is cultivated in so many widely separated countries—in all of which a rust epidemic is not liable to occur in any one year—which acts as a safeguard against a serious bread famine.

The coffee disease, also caused by a rust, is a striking example of the effect which a disease may have on the economic history of a country. In the earlier part of the second half of the 19th century, the coffee industry was the mainstay of the prosperity of Ceylon. About 1870 a hitherto unrecorded leaf disease appeared on the coffee bushes. As with many important plant parasites, the seriousness of this disease was not recognized at first. Within a few years the fungus had spread over the whole island and the coffee industry soon disappeared from Ceylon.

Perhaps the most outstanding instance of distress caused by a fungal disease is afforded by the great Irish potato famine in 1845 and 1846. The potato disease ("blight") had only appeared in Europe a few years previously, the causal fungus being, like the potato itself, a native of South America. The disease spread like wildfire over western Europe and in the seasons 1845 and 1846 almost completely destroyed the potato crop in Ireland. As the potato at that time constituted the staple food of the peasant population, the result of the epidemic was a famine of unprecedented severity.

The story of the coffee leaf disease in Ceylon has in recent years found a very close parallel in that of the chestnut blight in the United States. This disease first appeared in 1904 on a few trees in the neighbourhood of New York. Subsequent investigation showed that the causal fungus was a native of Eastern Asia where it occurs on certain native species of chestnut, but without causing appreciable damage. It had apparently been introduced into the United States on a consignment of chestnuts from the East, and there is every probability that if its importance had been recognized, the disease could have been stamped out in the early stages. As it was, the disease began to spread over the New England States and it soon became apparent that the fungus was much more destructive to the American sweet chestnut (*Castanea dentata*) than to the Asiatic forms. Control methods of the most elaborate nature were put in operation, but too late to be effective. At the present time, this disease has destroyed practically all the native chestnuts in the United States. (*See* CHESTNUT.)

Records of the complete extermination of an industry by fungal disease are fortunately not numerous. On the other hand it would be possible to multiply examples in which fungal diseases are an ever-present menace to particular cultivations. The most important single factor in the cultivation of many economic plants is the liability to certain fungal diseases.

METHODS OF CONTROLLING PLANT DISEASE

The checking of a plant disease, so that if not actually eliminated it is reduced to manageable proportions, is spoken of as its "control." This may be complete or partial. The methods of control may be divided into two main groups, first those which are put into practice by the grower himself, and second those which are enforced upon him by legislation. In the following discussion these will be considered separately.

Voluntary Control.—The adoption of control measures by the grower is subject to a number of severe restrictions. It is only with a certain number of crops that individual treatment of plants is possible, and in all but exceptional cases the economic consideration of cost is all-important. It is idle for the plant pathologist to suggest measures of control if the requirements of time and labour involved in the treatment are such as cannot be satisfied or if the ultimate gain to the grower is not obviously greater than the cost of the measures adopted. The control methods adopted may be directed to increasing the resistance of the plant to disease, or in the case of a parasitic disease may also be directed against the parasite. The former will be dealt with first.

Resistance.—For every plant there is a certain range of environmental conditions within which it grows best. If the conditions vary widely in any important respect from those which are ideal, the plant grows badly. A weakly growing plant is in general more susceptible to parasitic attack than is a strongly growing one, and the abnormal condition of the plant resulting from the unfavourable environment may in itself be so pronounced as to be called diseased. Good cultivation, therefore, which aims at giving the plant the optimal conditions for its growth, is the first line of treatment to be adopted with a view to lessening the incidence of disease.

The most approved methods of husbandry will not however guarantee freedom from plant diseases, nor are they always practicable. More special methods must therefore be adopted. In recent years it has become increasingly recognized that the main line of defence against many important diseases consists in the development of *immune* or *resistant varieties* of the host plant.

To obtain varieties of a crop plant which are resistant to a particular disease is in many cases not difficult. These may in fact exist among the varieties already in cultivation. If the resistant forms possess high merits in other respects—*e.g.*, in yielding power, in quality of product, etc.—then the problem of the particular disease is in large measure solved. Often, however, the resistant varieties which are already known to occur show certain disadvantageous features, and these may be so great as to outweigh the benefits conferred by the high disease resistance shown.

One method of obtaining a resistant *strain* from a commercial variety consists in growing the plants under conditions in which they are exposed to infection and selecting out for propagation those individuals which stand up successfully against the disease. This method has been adopted with great success in the development of strains resistant to some of the important wilt diseases (cotton, cabbage, etc.).

A more elaborate method consists in the artificial crossing of parents of known characteristics, followed by the sorting out of the different types which occur among the progeny. (*See* PLANT BREEDING.) This is the application to problems of disease of the principles of Mendelism (*q.v.*). Resistance to disease behaves as a single or multiple Mendelian factor, and is usually dominant in the immediate offspring.

Destruction of the Parasite.—The control of plant diseases by the adoption of measures against the fungus is best considered with reference to the life-history of the fungus and in particular to the manner in which it reinfects the growing crop after each period of winter dormancy.

If the fungus is a *soil parasite,* it may be possible to starve it out by ensuring that it does not come in contact with the particular crops on which it grows and multiplies. This involves a system of *rotation* of crops. The practice of crop rotation is justified for other agricultural reasons and is of great value in that it tends to check the multiplication of specific soil (and other) parasites. Some soil parasites however are able to live indefinitely on the humus material of the soil so that they cannot be starved out (*e.g.,* some wilt diseases), others may persist so long in the dormant form that the interval required between successive susceptible crops is too long to be economically practicable (*e.g.,* wart disease of potato).

The elimination of a parasite from the soil by any process of sterilization is generally impracticable on account of the expense involved. In greenhouse cultivation or in those cases where the main source of infection is the seed-bed, soil sterilization may be attempted. For this purpose, heat (*e.g.,* steam-heat as obtained from a boiler) or a fungicidal chemical such as formalin is generally used.

Preventive Measures.—If the disease is carried by the seed, the practical method of control consists either in the selection of seed known to be free from contamination or in some process of seed treatment devised to destroy the parasite without appreciably affecting the germinating capacity of the seed. If the fungus is present merely on the surface of the seed, treatment is generally simple. This consists in steeping the contaminated seed in solutions of various chemicals—formalin, copper sulphate, mercuric chloride, organic salts of mercury, etc.—for a suitable time. The fungus is killed by this treatment whereas the seed is little damaged on account of the protection afforded by its seed coat. Dusting the seed with various chemical powders is similarly effective.

A general palliative measure in the treatment of plant disease is to reduce the amount of infective material available. If the fungus overwinters on the dead remains of the previous year's crop, the latter should be disposed of, either by burning or by digging into the ground. Crop rotation, by segregating to some extent the current year's crop from last year's, is likewise useful.

One of the most important methods of protecting plants against the attack of air-borne parasites is by the use of fungicidal chemicals which are sprayed or dusted over the plants. The object aimed at here is to coat the surface of the plant with a thin but more or less continuous film of the fungicidal substance so that, when the air-borne spores of the parasite arrive, they are unable to initiate attack. Spraying or dusting, if properly carried out, prevents attack but is ineffective if the disease has already established itself. Thus an intimate knowledge of the life-history of the fungus with special reference to the date at which it emerges from its winter resting stage is of the greatest importance for success in spraying operations. The leaves and young shoots of the plant are readily injured by the action of poisonous chemicals, so that great care is necessary in the preparation and use of fungicides, otherwise greater damage may be done than that which it is intended to prevent. The spray, which consists of a very fine suspension in water of the fungicidal substance, is discharged under pressure in the form of a mist so that as far as possible the whole plant surface is covered. In practice various inert substances ("spreaders") are added in order to facilitate wetting of the leaves and adhesion of the spray. The basis of most sprays in commercial use is either copper or sulphur. To the former class belong the well known Bordeaux and Burgundy mixtures, prepared by adding solutions of copper sulphate to lime and soda respectively. To the latter belong such preparations as "liver of sulphur," "lime sulphur" and "colloidal sulphur."

Legislative Control.—The legislative enforcement of certain measures for the control of plant diseases actually dates back for several hundred years. Witness for example the Rouen act of 1660 for the control of wheat rust by the eradication of barberry bushes (*see* later). The full development of these measures however has only come about within the last twenty years. The Destructive Insects and Pests Act was passed by the British parliament in 1907 and a similar law, the National Plant Quarantine Act came into force in the United States in 1912. Practically all civilized countries adopted the same type of regulations and at much the same time.

Restriction of Imports.—As between one country and another, the effect of these enactments is to limit free trading in such plants or plant products as are considered likely to bring dangerous parasites into the importing country. The restrictions may amount to a complete embargo, as applies for instance to the import of English potatoes into the United States (on account of the wart disease) or of American gooseberry bushes into England (on account of mildew). In other cases import is allowed provided the material has been inspected by a responsible authority in the exporting country and warranted free from certain diseases. Such material is subjected to further inspection at the port of entry and if found contaminated may be destroyed. From the port it may be liberated directly to the trade or may be sent to a quarantine station, where it is grown in an isolated situation for such time as enables its freedom from disease to be fully established. These restrictive regulations may also be in force between different parts of the same country, as for instance, between the different states of the United States.

Domestic Control Measures.—Within the limits of any one country, legislative control may take the form of compulsory notification of certain diseases. The latter will then be inspected, and the appropriate measures—such as destruction of the infected material—enforced. A further measure is the placing of restrictions on the kind of crop which may be grown within certain infected areas. The legislation against wart disease of potato in England is an illustration of this type of control measure. Within an infected area (called a "scheduled" area) only immune varieties of potatoes may be grown. The enforcement of this kind of measure is very difficult unless suitable immune varieties or other substitute crops are available.

Legislative control of the type outlined above has naturally led to the creation of an inspection service, and further to a wide extension of facilities for advisory work and for the carrying out of research. This increased interest in problems of plant disease, arising from government intervention, is perhaps the most striking development in plant pathology which the 20th century has produced.

CLASSIFICATION OF PLANT DISEASES AND SPECIAL ACCOUNT

In the present section a brief account will be given of some of the more important plant diseases and under the following headings—

(*a*) Physiological Plant Diseases.
(*b*) Plant Diseases due to Bacteria.
(*c*) Plant Diseases due to Viruses.
(*d*) Plant Diseases due to Fungi and Slime-Fungi.
(*e*) Plant Diseases due to Higher Plants.

Physiological Plant Diseases.—Plants, like animals, may show deficiency diseases due to the lack of some important chemical constituent in their food supply. Thus a lack of iron salts in the soil produces the condition called "chlorosis," in which the green pigment of the plant, chlorophyll, fails to develop. Lack of potash, such as often occurs in poorly manured soils or in light soils leached by heavy rainfall, produces very characteristic symptoms of disease in certain plants, *e.g.*, potato, tobacco and cereals. Similarly for other essential food elements such as magnesium, phosphate and nitrogen. Conversely disease conditions may result from the presence of an excess of certain chemicals in the soil. To this class belong various kinds of chlorosis, due to excess of lime or manganese in the soil. The most important diseases of this type are those associated with the accumulation of soil alkali. These are met with in irrigated regions where they often constitute the chief agricultural problem.

Among diseases due to unsuitable environmental conditions may be cited those caused by too high temperature, such as sunscorch of leaves, heat canker, etc. The effects of too low temperature are familiar as frost injury to leaves, young shoots, fruit, etc., but a more important illustration is seen in the winter killing of trees in those countries which experience severe winter freezing. The development of "winter-hardy" varieties of cultivated plants is of great importance in countries possessing the continental type of climate.

Injuries due to noxious chemicals in the air are well shown by plants growing in industrial areas. The more important chemicals in this connection are gases, such as coal gas and sulphur dioxide, fumes such as sulphuric acid, and dusts such as soot and cement dust. The latter act by choking up the breathing pores of the plants, but this action is often accompanied by the poisonous effects of gases associated with the dust. In this connection should also be mentioned the injuries which arise from the injudicious use of chemical protective agents such as sprays.

Plant Diseases Due to Bacteria.—The most important diseases of this type are the fire blight (*Bacillus amylovorus*) of apples, pears and similar fruits; the angular leaf spot or black-arm disease of cotton (*Pseudomonas malvacearum*); the olive tubercle (*P. Savastanoi*); citrus canker (*P. citri*); various wilt diseases (*Bacillus tracheiphilus* in cucurbits, *B. solanacearum* in tomato, potato, etc.); soft rots of a number of vegetables (*B. carotovorus* and allied species); two leaf spot diseases of tobacco (*Bacterium angulatum* and *B. tabaci*); and crown gall (*P. tumefaciens*) on a large variety of herbaceous and woody plants.

Plant Diseases Due to Viruses.—This important group was formerly placed among the physiological diseases, but it is now known that they are of infectious or contagious nature. Detailed investigation has failed to show the presence of a visible parasite, but in other respects the resemblance to the parasitic type of disease is very close. The disease can in many cases be transmitted by the inoculation of the juice of a diseased plant into a healthy one. Where this simple method of transmission fails, infection of a healthy plant can be obtained by grafting on it a shoot of a diseased plant. In certain cases it has been proved that the juice of a diseased plant is able to convey infection after it has been filtered through a porcelain cup, whence the current view with regard to these diseases is that they are caused by filter-passing organisms. The symptoms of virus disease are confined to the shoot portions of the plant, and take the form typically of mottling ("mosaic") of the leaves, with as a rule a certain amount of puckering, distortion or inrolling. The habit of growth may also be affected, and often there is dwarfing, premature death, and a marked diminution in the yield. The chief agents of transmission are various leaf-biting or leaf-sucking insects, particularly aphides. The number of crop plants which are known to show virus diseases is very large and includes potato, tomato, tobacco, cucumber, clovers, spinach, hop, sugar cane, sugar beet, peach and many others. Certain kinds of ornamental variegation are also infectious and are thus not distinguishable from virus disease.

Diseases Due to Fungi and Slime-fungi.—These constitute by far the most numerous group of plant diseases. The species of fungi which cause plant disease are to be numbered by thousands and occur in all the main divisions into which fungi are classified (*see* FUNGI). In the majority of text books on plant pathology, these diseases are classified according to the systematic relationship of the causal fungus, but in some cases a grouping according to the crop plant affected or according to the type of symptom produced may offer certain advantages. In the present article, any systematic review of even the more important diseases is impossible. All that can be attempted is to indicate some of the more important groups or types.

The Slime-Fungi (*Myxomycetes*) are responsible for a few diseases of economic importance. The best known example is the finger-and-toe or club root of crucifers (turnip, swede, cabbage, etc.) due to the organism *Plasmodiophora brassicae*. This disease is remarkable for the large size of the hypertrophies produced on the roots of the affected plants.

The group of the Lower Fungi (*Phycomycetes*) includes two mportant disease-producing families. The more important of hese is the *Peronospora* family or downy mildews which cause mportant diseases of a great number of crops, potato, vine, hop, ettuce, several grasses and many others. The downy mildew of he potato (*Phytophthora infestans*) produces the most important disease of all, the potato blight, to which reference has already been made. Many seedling diseases ("damping off") also belong here. The most important member of the second family is the organism *Synchytrium endobioticum*, the cause of the black scab or wart disease of potato.

Within the group of the *Ascomycetes* there are numerous important parasites. Species of *Sclerotinia* produce the brown-rot or "mummy" diseases of apple, plum and similar fruits, being mong the most destructive orchard parasites. The family of the *Erysiphaceae* comprises the powdery mildews. These fungi cause he abundant formation on the plant of a powdery mass of summer pores, whence the name of the group. Crops of economic importance which are attacked by powdery mildews include cereals, lover, vine, hop, gooseberry, strawberry, apple, rose and oak. Species of *Exoascus* produce the leaf-curl disease of peaches and lmonds and a number of interesting if economically unimportant diseases such as witches' brooms on cherry and birch. To the group of *Ascomycetes* also belong such important diseases as ergot of grasses (*Claviceps purpurea*), apple canker (*Nectria galligena*), wheat scab (*Gibberella saubinetii*), black knot of plum (*Plowrightia morbosa*), chestnut blight (*Endothia parasitica*), and apple scab (*Venturia inaequalis*). The group *Basidiomycetes* includes three families of parasites of very great economic importance: the smuts, the rusts and the bracket fungi.

The smuts (*Ustilagineae*) are a peculiar group of parasites which live almost wholly within the host plant and usually direct their attack to the developing flower and fruit. The latter in the typical case is converted into a black powdery mass of spores which constitute the "smutted" head so characteristic of this type of disease. The most important examples are met with among the grasses—viz., the loose and covered smuts of barley, wheat, oats, rye, rice, maize, etc.

The rusts (*Uredineae*) include perhaps the most important of all plant parasites. The cereal rusts (*Puccinia graminis* and allied forms) are the best known and economically the most serious, but important parasites occur on apple, plum, coffee, Weymouth pine, and many others, especially herbaceous plants. A striking feature in the life history of some of these rusts is that they pass from one host species to another. Thus some forms of the wheat rust parasite have a stage on the barberry; the Weymouth pine blister rust passes to various species of currant. The elimination of the so-called "alternate host" offers a means of control for certain of these rusts. Hence the "barberry eradication campaign" which is being actively prosecuted in certain wheat-growing countries.

The bracket fungi (*Polyporaceae*) are a group which attack living trees and timber. These are generally wound parasites which gain entrance through broken branches or other injuries, destroy the wood of the tree, and from time to time produce the well-known bracket-like fructifications on the surface. Species of *Polyporus* and *Fomes* attack a large variety of growing trees.

Diseases due to Imperfect Fungi make up an enormous and miscellaneous list, including such as the following: many fruit rots (*Botrytis, Penicillium*), wilts (*Fusarium*), stripe disease of cereals (*Helminthosporium*), and an almost infinite number of leaf, stem and fruit spots (*Phoma, Septoria, Gloeosporium,* etc.).

Diseases Due to Higher Plants.—Parasites of this type are of great botanical interest, but as a rule of little economic importance. Well known examples are the mistletoe (which is a semi-parasite only, being able to manufacture its carbonaceous food from the air by means of its green leaves) and the dodder or love vine. These attach themselves to and parasitize the stems of other plants.

BIBLIOGRAPHY.—F. D. Heald, *Manual of Plant Diseases* (New York and London, 1926), gives a full bibliography (pp. 20–24) of general and specialized text-books. Current literature: *Phytopathology* (American Phytopathological Society, 1911 onwards); *Journal of Agricultural Research* (Washington, D. C., 1913 onwards); *Annals of Applied Biology* (London, 1914 onwards); *Zeitschrift für Pflanzenkrankheiten,* (Stuttgart, 1891 onwards); *Review of Applied Mycology* (Kew, England, 1922 onwards). The journal last mentioned gives full abstracts of all the current plant pathological literature. (W. BRO.)

PLANUDES, MAXIMUS (*c.* 1260–1330), Byzantine grammarian and theologian who flourished during the reigns of Michael VIII. and Andronicus II. Palaeologi, spent the greater part of his life as a monk in Constantinople. On entering the monastery he changed his original name Manuel to Maximus. Possessing a knowledge of Latin remarkable for his time he was sent by Andronicus II. in 1327 on an embassy to remonstrate with the Venetians for their attack upon the Genoese settlement in Pera. Planudes, especially by his translations, paved the way for the introduction of the Greek language and literature into the West.

He is the author of a Greek grammar, a biography of Aesop and a prose version of his fables, certain scholia, various original poems. His numerous translations from the Latin included Cicero's *Somnium Scipionis* with the commentary of Macrobius: Caesar's *Gallic War;* Ovid's *Heroides* and *Metamorphoses;* Boetius, *De consolatione philosophiae;* Augustine, *De trinitate.* He also edited a supplement to the Anthology known as *Appendix Planudea.*

See Fabricius, *Bibliotheca graeca,* ed. Harles, xi. 682; theological writings in Migne, *Patrologia graeca.* cxlvii.; correspondence, ed. M. Treu (1890), with a valuable commentary; K. Krumbacher, *Geschichte der byzantinischen Literatur* (1897); J. E. Sandys, *Hist. of Class. Schol.* (1906), vol. i.

PLAQUE, a small flat plate or tablet, applied particularly to rectangular or circular ornamental plates or tablets of bronze, silver, lead or other metal, or of porcelain or ivory. Small plaques, called plaquettes, in low relief in bronze or lead, were produced in great perfection in Italy at the end of the 15th and beginning of the 16th centuries, and were usually copies of ancient engraved gems, earlier goldsmith work and the like.

PLASSEY (Palāsi), village of Bengal, scene of Clive's victory on June 23, 1757, over the forces of the nawab Suraj-ud-Dowlah. Clive, with 1,100 European and 2,100 native troops, and 10 field-pieces, took the field against the nawab, who had 50,000 men, 53 heavy guns, and some French artillery under M. de St. Frais. Only the river Bhagirathi separated Clive's little force from the entrenched camp of the enemy, when the English leader, for once undecided, called a council of war. Clive and the majority were against fighting, Major Eyre Coote, of the 39th Foot, and a few others for action. Coote's soldierly advice powerfully impressed Clive, and after deep consideration he altered his mind and issued orders to cross the river. After a fatiguing march, the force bivouacked in a grove near Plassey early on the 23rd. The nawab's host came out of its lines and was drawn up in a huge semicircle almost enclosing the little force in the grove, and St. Frais's gunners on the right wing opened fire. Clive replied, and was soon subjected to the converging fire of 50 heavy guns. For hours the unequal fight was maintained, until a rainstorm stopped it. The English covered up their guns, but the enemy took no such precaution. Mir Mudin, the only loyal general of the nawab's army, thinking that Clive's guns were as useless as his own, made a disastrous cavalry charge upon them; he lost his own life, and his colleagues then had the game in their hands. Mir Jagar persuaded the nawab to retire into the entrenchments. St. Frais stood fast until one of Clive's officers, Major Kilpatrick, successfully drove him in. Clive followed up this success by cannonading the camp at close range. But the rank and file of the native army, ignorant of the treachery of their leaders, made a furious sortie. For a time Clive was hard pressed, but his cool generalship held its own against the undisciplined valour of the enemy, and, noticing Mir Jagar's division in his rear made no move against him, he led his troops straight against the works. After a short resistance, made chiefly by St. Frais, the whole camp fell into his hands. At a cost of 23 killed and 49 wounded this day's work decided the fate of Bengal. Although the historic grove has disappeared, a monument has been erected to commemorate the victory.

PLASTER OF PARIS, $2CaSO_4, H_2O$, a hemihydrated variety of gypsum (dihydrated calcium sulphate, $CaSO_4.2H_2O$) which forms a cement when treated with water (*see* CEMENT). It obtained its name in consequence of being manufactured by the calcination of gypsum in the neighbourhood of Paris.

PLASTER-WORK. Plastering is one of the most ancient of handicrafts employed in connection with building operations, the earliest evidence showing that the dwellings of primitive man were erected in a simple fashion with sticks and plastered with mud. Soon a more lasting and sightly material was employed to take the place of mud or slime, and that perfection in the compounding of plastering materials was approached at a very remote period is proved by the fact that some of the earliest plastering which has remained undisturbed excels in its scientific composition that which is used at the present day. The pyramids in Egypt contain plaster-work executed at least 4,000 years ago (probably much earlier) and yet existing, hard and durable. Indeed the principal tools of the plasterer of that time were practically identical in design, shape and purpose with those used to-day. For their finest work the Egyptians used a plaster made from calcined gypsum just like the plaster of paris of the present time, and their methods of plastering on reeds resemble in every way our "lath, plaster, float and set" work. Hair was introduced to strengthen the "stuff," and the whole finished somewhat under an inch thick.

Very early in the history of Greek architecture we find (*e.g.*, at Mycenae) the use of plaster of a fine white lime stucco. The art had reached perfection in Greece more than five centuries before Christ, and plaster was frequently used to cover temples externally and internally, in some cases even where the building was of marble. It formed a splendid ground for decorative painting, which at this period of Grecian history had reached a very high degree of beauty. The temple of Apollo at Bassae, built of yellow sandstone about 470 B.C., is an excellent example. Pavements of thick, hard plaster, stained with various pigments, were commonly laid in Greek temples. In England the walls of large houses were formerly plastered above the wainscoting and coloured, while the ornamented plaster ceilings of the time of Henry VIII., Elizabeth and James I., are still the admiration of lovers of the art. Still earlier specimens of the plasterer's skill are extant in the pargeted and ornamented fronts of half-timbered houses. With regard to the smaller buildings, comprising small dwelling-houses and cottages, the general application of plaster is of comparatively late date; for wainscoted walls and boarded ceilings or naked joists alone are frequently found in houses of not more than a century old both in England and on the Continent.

Wood and Metal Lathing.—Wood laths are narrow strips of some straight-grained wood, generally Baltic or American fir, in lengths of from two to four or five feet to suit the distances at which the timbers of a floor or partition are set. Laths are about an inch wide, and are made in three thicknesses; "single" (⅛ to $\frac{3}{16}$in. thick), "lath and a half" (¼in. thick), and "double" (⅜ to ½in. thick). The thicker laths should be used in ceilings, to stand the extra strain, and the thinner variety in vertical work such as partitions, except where the latter will be subjected to rough usage. Laths are nailed with a space of about ⅜in. between them to form a key for the plaster, and they must be nailed so as to break joint in bays three or four feet wide with ends butted one against the other. By breaking the joints of the lathing in this way, the tendency for the plaster to crack along the line of joints is diminished and a better key is obtained. Every lath should be nailed at each end and wherever it crosses a joist or stud. All timbers over three inches wide should be counter-lathed, that is, have a fillet or double lath nailed along the centre upon which the laths are then nailed. This is done to preserve a good key for the plaster. Walls liable to damp are sometimes battened and lathed in order to form an air cavity between the damp wall and the plastering.

Lathing of metal, either of wire or in the form of perforated sheets, is extensively used on account of its fire-proof and lasting quality. There are very many kinds of this material made in different designs under various patents. A lathing has been introduced formed of thin wooden rods wired together at ¼in. intervals. This can be fixed around curves, and economizes plaster.

Lathing nails are usually of iron, cut, wrought or cast—and in the better class of work they are galvanized to prevent rusting. Zinc nails are sometimes used, but are costly.

Materials for Plaster.—The lime principally used for internal plastering is that calcined from chalk or other nearly pure limestone, and is known as fat, pure, chalk or rich lime. Hydraulic limes (*see* BRICKWORK and MORTAR) are also used by the plasterer, chiefly for external work. Perfect slaking of the calcined lime before use is very important as, if used in a partially slaked condition, it will "blow" when in position and blister the work. Lime should therefore be run as soon as the building is begun, and at least three weeks should elapse between the operation of running the lime and its use.

Hair is used in plaster as a binding medium, and gives tenacity to the material. Ox-hair, which is sold in three qualities, is the kind usually specified; but horsehair, which is shorter, is sometimes substituted in its stead or mixed with the ox-hair in the lower qualities. Good hair should be long, strong, and free from grease and dirt, and before use must be well beaten to separate the lumps. In America, goats' hair is frequently used, though it is not so strong as ox-hair. The quantity used in good work is one pound of hair to two or three cubic feet of coarse stuff.

Manila hemp fibre has been used as a substitute for hair. As a result of experiments to ascertain its strength as compared with that of other materials, it was found that plaster slabs made with Manila hemp fibre broke at 195lb., plaster mixed with Sisal hemp at 150lb., jute at 145lb., and goats' hair at 144½lb. Another test was made in the following manner. Two barrels of mortar were made up of equal proportions of lime and sand, one containing the usual quantity of goats' hair, and the other Manila fibre. After remaining in a dry cellar for nine months the barrels were opened. It was found that the hair had been almost entirely eaten away by the action of the lime, and the mortar consequently broke up and crumbled quite easily. The mortar containing the Manila hemp, on the other hand, showed great cohesion, and required some effort to pull it apart, the hemp fibre being apparently quite uninjured. Sawdust has been used as a substitute for hair and also instead of sand as an aggregate. It will enable mortar to stand the effects of frost and rough weather. It is useful sometimes for heavy cornices and similar work, as it renders the material light and strong. The sawdust should be used dry.

Some remarks are made on the ordinary sands for building in the articles on BRICKWORK and MORTAR. For fine plasterer's work special sands, not hitherto referred to, are used, such as silver sand, which is used when a light colour and fine texture are required. In England this fine white sand is procured chiefly from Leighton Buzzard.

External Work.—For external work Portland cement is undoubtedly the best material on account of its strength, durability and weather resisting properties. The first coat or rendering is from $\frac{1}{2}$ to [illegible]in. thick, and is mixed in the proportions of from one part of cement to two of sand to one part to five of sand. The finishing or setting coat is about $\frac{3}{16}$in. thick, and is worked with a hand float on the surface of the rendering, which must first be well wetted.

Stucco is a term loosely applied to nearly all kinds of external plastering, whether composed of lime or of cement. The principal varieties of stucco are common, rough, trowelled and bastard. Common stucco for external work is usually composed of one part hydraulic lime and three parts sand. The wall should be sufficiently rough to form a key and well wetted to prevent the moisture being absorbed from the plaster. Portland cement is used for all but the commonest external work. White Portland cement, made in the United States and France, is very successfully used with white sand to give an excellent stucco closely resembling stone and very durable.

Rough stucco is used to imitate stonework. It is worked with a hand float covered with rough felt, which forms a sand surface on the plaster. Lines are ruled before the stuff is set to represent the joints of stonework. *Trowelled stucco,* the finishing coat of this work, consists of three parts sand to two parts fine stuff. A very fine smooth surface is produced by means of the hand float. *Bastard stucco* is of similar composition, but less labour is expended on it. It is laid on in two coats with a skimming float, scoured off at once, and then trowelled. Stucco may be executed in colours, the desired tints being obtained by mixing with the lime various oxides. Black and greys are obtained by using forge ashes in varying proportions, greens by green enamel, reds by using litharge or red lead, and blues by mixing oxide or carbonate of copper with the other materials.

Rough-cast or *Pebble-dash* plastering is a rough form of external plastering in much use for country houses. In Scotland it is termed "harling." It is one of the oldest forms of external plastering. In Tudor times it was employed to fill in between the woodwork of half-timbered framing. When well executed with good material this kind of plastering is very durable. Rough-casting is performed by first covering the wall or laths with a coat of well-haired coarse stuff composed either of good hydraulic lime or of Portland cement. This layer is well scratched to give a key for the next coat, which is also composed of coarse stuff knocked up to a smooth and uniform consistency. While this coat is still soft, gravel, shingle or other small stones are evenly thrown on with a small scoop and then brushed over with thin lime mortar to give a uniform surface. The shingle is often dipped in hot lime paste, well stirred up, and used as required.

Sgraffito (Italian for "scratched") is scratched ornament in plaster. Scratched ornament is the oldest form of surface decoration, and at the present day it is much used on the Continent, especially in Germany and Italy, in both external and internal situations. Properly treated, the work is durable, beautiful and inexpensive. The process is carried out by applying a first coat or rendering of Portland cement and sand, in the proportion o one to three, laid on about $\frac{1}{2}$in. thick; then following with th colour coat, which is sometimes put on in patches of different tint as required for the finished design. When this coat is nearly dry it is finished with a smooth-skimming, $\frac{1}{12}$ to $\frac{1}{8}$in. thick, of Parian selenitic or other fine cement or lime, only as much as can b finished in one day being laid on. Then by pouncing through th pricked cartoon, the design is transferred to the plastered surface Broad spaces of background are now exposed by removing th finishing coat, thus revealing the coloured plaster beneath, an following this the outlines of the rest of the design are scratche with an iron knife through the outer skimming to the underlyin tinted surface. Sometimes the coats are in three different colours such as brown for the first, red for the second and white or gre for the final coat. The pigments used for this work include Indian red, Turkey red, Antwerp blue, German blue, umber, ochre purple brown, bone black or oxide of manganese for black. Combinations of these colours are made to produce any desired tone

Internal Plastering.—Lime plastering is composed of lime sand, hair and water in proportions varying according to th nature of the work to be done. In all cases good materials, wel mixed and skilfully applied, are essential to a perfect result. Whe brickwork is to receive plaster, it is all-important that its surfac should be rough enough to form a key, or, alternatively, that th joints should be well raked out. Plaster is applied in successiv coats or layers on walls or lathing, and gains its name from th number of these coats. "One coat" work is the coarsest an cheapest class of plastering, and is limited to inferior buildings such as outhouses, where merely a rough coating is required t keep out the weather and draughts. This is described as "render" on brickwork, and "lath and lay" or "lath and plaster one coat" on studding. "Two coat" work is often used for factories o warehouses and the less important rooms of residences. The first coat is of coarse stuff finished fair with the darby float and scoured. A thin coat of setting stuff is then laid on, and trowelled and brushed smooth. "Two coat" work is described as "render and set" on walls, and "lath, plaster and set," or "lath, lay and set" on laths. "Three coat" work is usually specified for all good work. It consists, as its name implies, of three layers of material, and is described as "render, float and set" on walls and "lath, plaster, float and set," or "lath, lay, float and set," on lathwork. This makes a strong, straight, sanitary coating for walls and ceilings. The process for "three coat" work is as follows: For the first coat a layer of well-haired coarse stuff, about $\frac{1}{2}$in. thick, is put on with the laying trowel. This is termed "pricking up" in London, and in America "scratch coating." It should be laid on diagonally, each trowelful overlapping the previous one. When on laths the stuff should be plastic enough to be worked through the spaces between the laths to form a key, yet so firm as not to drop off. The surface while still soft is scratched to give a key for the next coat, which is known as the second or "floating coat," and is $\frac{1}{4}$ to $\frac{3}{8}$in. thick. In Scotland this part of the process is termed "straightening" and in America "browning," and is performed when the first coat is dry, so as to form a straight surface to receive the finishing coat. Four operations are involved in laying the second coat, namely, forming the screeds; filling in the spaces between the screeds; scouring the surface; keying the face for finishing. Wall and ceiling screeds are plumbed and levelled. Screeds are narrow strips of plastering, carefully plumbed and levelled, so as to form a guide upon which the floating rule is run, thus securing a perfectly horizontal or vertical surface, or, in the case of circular work, a uniform curve. The "filling in," or "flanking," consists of laying the spaces between the screeds with coarse stuff, which is brought flush with the level of the screeds with the floating rule.

The "scouring" of the floating coat is of great importance, for it consolidates the material, and, besides hardening it, prevents it from cracking. It is done by the plasterer with a hand float which he applies vigorously with a rapid circular motion, at the same time sprinkling the work with water from a stock brush in the other hand. Any small holes or inequalities are filled up as he proceeds. The whole surface should be uniformly scoured two or three times, with an interval between each operation of from six to twenty-four hours. This process leaves the plaster with a close-grained and fairly smooth surface, offering little or no key to the coat which is to follow. To obtain proper cohesion, however, a roughened face is necessary, and this is obtained by "keying" the surface with a wire brush or nail float, that is, a hand float with the point of a nail sticking through and projecting about ⅛in.; sometimes a point is put at each corner of the float. After the floating is finished to the walls and ceiling, the next part of internal plastering is the running of the cornice, followed by the finishing of the ceiling and walls.

The third and final coat is the "setting coat," which should be about ⅛in. thick. In Scotland it is termed the "finishing," and in America the "hard finish" or "putty coat." Considerable skill is required at this juncture to bring the work to a perfectly true finish, uniform in colour and texture. Setting stuff should not be applied until the floating is quite firm and nearly dry, but it must not be too dry or the moisture will be drawn from the setting stuff.

The coarse stuff applied as the first coat is composed of sand and lime, usually in proportions approximating two to one, with hair mixed into it in quantities of about a pound to two or three cubic feet of mortar. It should be mixed with clean water to such a consistency that a quantity picked up on the point of a trowel holds well together and does not drop. Floating stuff is of finer texture than that used for "pricking up," and is used in a softer state, enabling it to be worked well into the keying of the first coat. A smaller proportion of hair is also used. Fine stuff mixed with sand is used for the setting coat. Fine stuff, or lime putty, is pure lime which has been slaked and then mixed with water to a semi-fluid consistency, and allowed to stand until it has developed into a soft paste. For use in setting it is mixed with fine washed sand in the ratio of one to three.

For cornices and for setting when the second coat is not allowed time to dry properly, a special compound must be used. This is often "gauged" stuff, composed of three or four parts of lime putty and one part of plaster of paris, mixed up in small quantities immediately before use. The plaster in the material causes it to set rapidly, but if it is present in too large a proportion the work will crack in setting.

The hard cements used for plastering, such as Parian, Keene's and Sirapite, are laid generally in two coats, the first of cement and sand ½ to ¾in. in thickness, the second or setting coat of neat cement about ⅛in. thick. These and similar cements have gypsum as a base, to which a certain proportion of another substance, such as alum, borax or carbonate of soda, is added, and the whole baked or calcined at a low temperature. The plaster they contain causes them to set quickly with a very hard smooth surface, which may be painted or papered within a few hours of its being finished.

Mouldings.—Plain, or unenriched, mouldings are formed with a running mould of zinc cut to the required profile. Enrichments to suit a scheme may be added after the main outline moulding is set, being cast in moulds of gelatine or plaster of paris. For a cornice moulding two running rules are usual, one on the wall, the other on the ceiling, upon which the mould is worked to and fro by one workman, while another man roughly lays on the plaster to the shape of the moulding. The mitres at the angles are finished off with joint rules made of sheet steel of various lengths, three or four inches wide, and about ⅛in. thick, with one end cut to an angle of about 30°. In some cases the steel plate is let into a "stock" or handle of hardwood.

Cracks in plastering may be caused by settlement of the building, and by the use of inferior materials or by bad workmanship, but apart from these causes, and taking the materials and labour as being of the best, cracks may yet ensue by the too fast drying of the work, caused through the laying of plaster on dry walls which suck from the composition the moisture required to enable it to set, by the application of external heat or the heat of the sun, by the laying of a coat upon one which has not properly set, the cracking in this case being caused by unequal contraction, or by the use of too small a proportion of sand.

For partitions and ceilings, plaster slabs (often of fibrous plaster) are in very general use when work has to be finished quickly. For ceilings they require simply to be nailed to the joists, the joints being made with plaster, and the whole finished with a thin setting coat. In some cases, with fire-proof floors, for instance, the slabs are hung up with wire hangers so as to allow a space of several inches between the soffit of the concrete floor and the ceiling. For partitions the slabs frequently have the edges tongued and grooved to form a better connection; often, too, they are holed through vertically, so that, when grouted in with semi-fluid plaster, the whole partition is bound together, as it were, with plaster dowels. Where very great strength is required the work may be reinforced by small iron rods through the slabs. This forms a very strong and rigid partition which is at the same time fire-resisting and of light weight, and when finished measures only from two to four inches thick. The slabs may be obtained either with a keyed surface, which requires finishing with a setting coat when the partition or ceiling is in position, or a smooth finished face, which may be papered or painted immediately the joints have been carefully made. Partitions are formed with one or other of the forms of metal lathing referred to, fixed to iron uprights and plastered on both sides.

Fibrous Plaster.—Fibrous plaster is given by plasterers the suggestive name "stick and rag," and this is a rough description of the material, for it is composed of plaster laid upon a backing of canvas stretched on wood. It is much used for ceilings, partitions, mouldings, circular and enriched casings to columns and girders, and ornamental work, which, being worked in the shop and then nailed or otherwise fixed in position, saves the delay often attendant upon the working of ornament in position.

Desachy, a French modeller, took out in 1856 a patent for "producing architectural mouldings, ornaments and other works of art, with surfaces of plaster," with the aid of plaster, glue, wood, wire and canvas or other woven fabric. The modern use of this material may be said to have started then, but the use of fibrous plaster was known and practised by the Egyptians long before the Christian era; for ancient coffins and mummies still preserved prove that linen stiffened with plaster was used for decorating coffins and making masks. Cennino Cennini, writing in 1437, says that fine linen soaked in glue and plaster and laid on wood was used for forming grounds for painting. Canvas and mortar were in general use in Great Britain up to about 1850. This work is also much used for temporary buildings.

It is a notable fact that the post-war rise of plasterers' wages in Great Britain and the United States, combined with the great scarcity of skilled workmen and other considerations, led to a considerable increase in the use of substitutes for plaster-work. Various "boards," made of woodpulp and other materials, plywood, and asbestos-cement sheets, have come largely into use for the finishing of walls and ceilings.

See G. R. Burnell, *Limes, Cements Mortars and Mastics* (5th ed., 1865); F. M. Simpson and others, *Building Construction* (1910 and 1913); Rivington's *Notes on Building Construction* (new ed., 1915), Part III.; W. Millar, *Plastering, Plain and Decorative* (4th ed., 1927); and the works on architecture of Robert and James Adam. *See* also E. C. Eckel, *Cements, Limes and Plasters* (1922); M. Jourdain, *English Decorative Plaster Work* (1926); A. H. Telling, *A.B.C. of Plastering* (1927). (X.; L. C. M.)

PLATA, RIO DE LA or **RIVER PLATE,** a funnel-shaped estuary, on the east side of South America, extending west-north-west from the sea about 170 miles. The discovery of the South sea by Balboa, then governor of Castilla del Oro, of which Darien formed a part, created a lively desire to learn something of its coast-line, and the year following (in 1514), the Spanish monarch concluded a navigation contract with Juan Diaz de Solis, then Piloto Mayor, to search for a strait connecting the Atlantic with the newly found ocean. De Solis set sail from the port of Lepe on Oct. 8, 1515, reached the Bay of Rio de Janeiro on Jan. 1, 1516, and continuing southward to lat. 35° entered the great estuary now known as the Plata, which, for a short period of time, was called the de Solis and the Mar Dulce. Ascending it to the vicinity of the island of Martin Garcia, near the mouth of the Paraná river, de Solis was ambushed and killed early in 1516 by Guarani Indians. In 1520 Magellan explored the Rio de la Plata, and discovered and navigated the straits which bear his name. In 1526 Cabot ascended the Mar Dulce, discovered the Paraná river and reached a point on the Paraquay near the site of the present city of Asunción. Here he obtained by barter from Guarani Indians silver ornaments. The receipt of these silver baubles caused the name of Rio de la Plata to be applied to the third greatest river of the western continent.

The extreme breadth of the river at its mouth is 138 miles. It narrows quickly to 57m. at Montevideo, and to 25m. at its head, where it receives the Paraná and Uruguay rivers. Its northern or Uruguayan shore is somewhat elevated and rocky, while the southern or Buenos Airean one is very low. The whole estuary is very shallow, and in no place above Montevideo exceeds 36ft. in depth at low water. The bottom generally consists of sand covered with from 10 to 20ft. of water. A dredged channel of about 22ft. in depth leads from the port of Buenos Aires 20m. east to deep water. Winds and tides considerably affect the depth of the channel. The Plata is simply the estuarine receptacle of two mighty streams, the Uruguay and Paraná which drain the Plata basin. This has an area of 1,198,000sq.m., or over two and one-half times that of the Pacific slope of the Andes, and comprises the most fertile, healthiest and best part of Brazil, a large portion of the Argentine republic, the whole of Paraguay and south-eastern Bolivia, and most of Uruguay.

The Uruguay and Affluents.—The Uruguay river has a length of about 1,000 miles. Many small streams from the western slope of the Brazilian Serra do Mar unite, in about 27° 45′ S., to form this river, which then flows W.N.W., serving as the boundary between the States of Santa Catharina and Rio Grande do Sul, as far as 52° W., near which it receives a considerable tributary from the north, called the Pepiri-guazú. Between 27° 58′ and 33° 34′ S. three important tributaries join it from the east—the Ipui-guazú, the Ibicui and the Negro.

The Pepiri-guazú in its lower course is about 250ft. wide, but higher up it narrows to about 30ft., and runs with great violence between high wooded banks. It is navigable for canoes for about 70m. above its mouth, as far as its first fall. The Rio Negro has a delta of several large islands at its confluence with the Uruguay. Its head-waters are in the southern part of Rio Grande do Sul, but the main river belongs entirely to the State of Uruguay. Its lower reaches are navigable for craft of moderate draught.

From its source in the coast range of Brazil the Uruguay runs through open, hilly country, and then enters a forest belt of high lands. At the river Pepiri-guazú it turns suddenly to the south-west, and continues this course to its junction with the Paraná and Plata. Near Fray Bentos, 61m. before reaching the Plata, it forms a great lake, about 56m. long and from 4 to 6m. wide. At Punta Gorda, where it debouches into the Plata, it is about 1m. wide, but is 90ft. deep. From the Pepiri-guazú junction its banks are high and covered with forest as far down as 27° 30′ S., where the river is 2,300ft. wide and from 10 to 40ft. deep. The Uruguay is much obstructed by rocky barriers. Four miles below its confluence with the Pepiri-guazú it has a cataract, about 8m. long with a total fall of 26ft. at low water. The river near the Pepiri-guazú is 1,550ft. wide, but about 1½m. before reaching the cataract its width is reduced to 600ft. Along the cataract it is closed in between high precipitous walls of black rock only 70ft. apart. Above Punta Gorda, 212m., is the Salto Grande, which has a length of 15m. of rapids, the greatest single fall being 12ft., and the difference of level for the entire length of the reefs 25ft. Nine miles below the Salto Grande is the Salto Chico, which bars navigation during six months of the year, but in flood-time may be passed in craft drawing 5ft. of water. The Uruguay can be navigated at all seasons by vessels of 4½ft. draught as far up as the Salto Chico, and of 14ft. up to Paysandú for a greater part of the year. Fray Bentos may be reached all the year round by any vessel that can ascend the Paraná. Above the navigable lower river there is launch and canoe navigation for many hundreds of miles upon the main artery and its branches, between the rapids which are met with from time to time. The Uruguay has its annual floods, due to the rains in its upper basin. They begin at the end of July and continue to November, attaining their maximum during September and October. Except in floods, it is a clear-water stream, and even at its highest level carries comparatively little silt.

The Paraná and Its Affluents.—The Paraná (the "Mother of the Sea" in Guarani) drains a vast area of southern Brazil. It is formed by the union of the Rio Grande and Paranáhyba, and is about 1,600m. long from its source in Goyaz to its junction with the Paraguay, and thence 600 more to the Plata estuary. Its average width for the latter length is from 1 to 3m. Its Rio Grande branch descends from the slope of the Serra da Mantiqueira, in the region where the orographic system of Brazil culminates near the peak of Itatiaia-assú, almost in sight of Rio de Janeiro. It is about 680m. long, but only navigable in the stretches between the many reefs, falls and rapids which interrupt its regular flow.

Besides these rivers, the Paraná has many long and powerful affluents from the Brazilian States of São Paulo and Paraná. Most of them, although obstructed by rapids, are navigable for launches and canoes. Among the eastern tributaries are the Tiété, the Paraná-panema, formerly known as the Anemby, and the Iguazú. The Paraná-panema is about 600m. long, and rises in an offshoot of the Serra Paranápicaba which overlooks the Atlantic ocean. It is navigable for only 30m. above its mouth.

The Iguazú, also called the Rio Grande de Curutiba, has its sources on the slopes of the Serra do Mar of Brazil, and flows nearly west, through thick forests, along the line of 26° South. Its navigation is difficult even for small craft, as it is full of reefs, rapids and cataracts. Sixteen miles above its mouth is the magnificent Salto del Iguazú, sometimes called the Victoria Fall, round which canoes have to be transported 37m. before quiet water is again reached. The width of the falls, measured along their crest or edge, is 2½m.; part of the river takes two leaps of about 100ft. each, but a portion of it plunges down the whole depth in unbroken mass. Its mouth is about 800ft. wide, and the depth in mid-river 40ft.

The Paraná has unobstructed navigation for about 400m. between the Falls of Urubuponga and the Falls of Guayra, in 24° 3′ S., where it forms a lake 4½m. long and 2½m. wide, preparatory to breaching the Serra de Mbaracayú, which there disputes its right of way. It has torn a deep gorge through the mountains for a length of about 2m., where it is divided into several channels, filled with rapids and cataracts. It finally gathers its waters into a single volume, to plunge with frightful velocity through a long cañon only about 200ft. wide. From these so-called falls of Guayra or "Sete Quedas," as far as its confluence with the Paraguay river, the Paraná has carved a narrow bed through an immense cap of red sandstone, along which it sometimes flows with great rapidity, occasionally being interrupted by dangerous narrows and rapids, where the banks in some places close in to a width of 450 to 600ft., although the average is from 1,200 to 1,600 feet. At the south-east angle of Paraguay the Paraná is turned westwards; but before escaping from its great sandstone bed it is obstructed by several reefs, notably at the rapids of Apipé, which are the last before it joins the placid Paraguay, 130m. farther on.

The Paraguay.—The river Paraguay, the main affluent of the Paraná, rises in Matto Grosso, in the vicinity of the town of Diamantino, about 14° 24′ South. It flows south-westwards, as far as Villa Maria, along the foot of the high plateau which divides it from the Cuyabá river to the east, and then, turning southwards, soon reaches the morass expansion of Xarayes, which it traverses for about 100m. A few miles below Villa Maria it receives an affluent from the north-west, the Jaurá, which has its source nearly in contact with the head-waters of the Guaporé branch of the river Madeira. From the junction of the São Lourenço (or Cuyabá) with the river Paraguay, the latter, now a great stream, moves sluggishly southwards, spreading its waters, in the rainy season, for hundreds of miles to the right and left, as far south as 20°, turning vast swamps into great lakes—in fact, temporarily restoring the region, for thousands of square miles, to its ancient lacustrine condition.

On the west side of the upper Paraguay, between about 17° 30′ and 19° S., are several large, shallow *lagunas* or lakes which receive the drainage of the southern slopes of the Chiquitos sierras, but represent mainly the south-west overflow of the vast morass of Xarayas. The principal of these lakes, naming them from north to south, are the Uberaba, the Gaiba, Mandioré and the "Bahia" de Caceres. The Uberaba is the largest. It is in great part surrounded by high ground and hills, but its southern coast is swampy and flooded during the rainy season. The west shore is historic. Here, in 1543, the *conquistador,* Martinez de Irala, founded the "Puerto de los Reyes," with the idea that it might become the port for Peru; and from Lake Gaiba several expeditions, in Spanish colonial days, penetrated 500m. across the Chaco to the frontier of the empire of the Incas. At the Puerto de los Reyes Bolivia laid out a town in Dec. 1900, in the forlorn hope that the "Port" may serve as an outlet for that commercially suffocated country, there being no other equally good accessible point for Bolivia on the Paraguay river.

South of the São Lourenço, the important rivers entering the Paraguay from the east are the Taquary, which rises in the Serra Cayapó, on the southern extension of the Matto Grosso tableland; the Mondego, with many branches, draining a great area of extreme southern Matto Grosso, and the Apá, which forms the boundary between Paraguay and Brazilian Matto Grosso.

The Pilcomayo.—The Pilcomayo rises among the Bolivian Andes north of Potosí and north-west of Sucre, races down the mountains to their base, crosses the Chaco plains, and pours into the river Paraguay near Asunción. It does not receive any branch of importance until it reaches about 21° S., where it is joined from the south-west by the river Pelaya, upon which Tupiza, the most southerly city of Bolivia, is situated. Just below the junction is the fall of Guarapetendi, 23ft. high. From this point to the mouth of the Pilcomayo the distance in a straight line is 480m., although by the curves of the river, which is extremely tortuous, it is about double that distance. According to Storm, who quotes Captain Baldrich, the river bifurcates at 21° 51′ S., but again becomes a single stream at 23° 43′, the right channel being the greater in volume. It is probable that between 23° and 24° S. it throws three great arms to the river Paraguay, the upper portions of which have yet to be explored, but the lower parts have been examined for 100 to 200m. up from the Paraguay. From 180 to 200m. above its mouth the Pilcomayo filters through a vast swamp about 100m. in diameter, through which there is no principal channel. This swamp, or perhaps shallow lagoon, is probably partly drained by the river Confuso, which reaches the Paraguay between the Pilcomayo and Macá. A northern branch of the Pilcomayo, the Fontana, the junction being at 24° 56′ S., is probably also a drainage outlet of the same great swamp.

For the first 100m. below the Fall of Guarapetendi the Pilcomayo is from 600 to 1,000ft. wide, but it so distributes its waters through its many bifurcations, and loses so much from infiltration and in swamps, and by evaporation from the numerous lagoons it forms on either side of its course, that its channel is greatly contracted before it reaches the Paraguay. From Sucre to the Andean margin of the Chaco, a distance of about 350m. by the river, the fall is at least 8,000ft.—a sufficient indication that its upper course is useless for purposes of navigation. Its lower course is of little value for commercial purposes.

The Bermejo.—The Bermejo river flows parallel to the Pilcomayo, and enters the Paraguay a few miles above the junction of this with the Paraná. Its numerous sources are on the eastern frontage of the inland Andes, between the Bolivian town of Tarija and the Argentine city of Jujuy. In 23° 50′ S. the Bermejo receives its main affluent, the San Francisco, from the south-west. The latter has its source in about 22° 30′ S., and, under the name of Rio Grande, runs directly southwards, in a deep mountain valley, as far as Jujuy. It then turns eastwards for 50m., and is joined by the Lavayen from the south-west. These two streams form the San Francisco, which, from their junction, runs north-eastwards to the Bermejo. From its junction with the latter stream the Bermejo flows south-eastwards to the Paraguay with an average width in its main channel of about 650ft., although narrowing at times to 160 and even 100. In its course, however, it bifurcates and ramifies into many channels, forming enormous islands, and frequently leaves old beds for new ones.

Since the exploration of the Bermejo by Patiño in 1721, it has often been examined from its sources to its mouth, with a view to ascertaining its navigability. Like the Pilcomayo, the Bermejo is of little use owing to swift currents, shoals, quicksands, snags and fallen trees.

The Salado.—The Salado, about 250m. south-west of and approximately parallel to the Bermejo, is the only great tributary which the Paraná receives from the west below its confluence with the Paraguay. Its extreme head-waters, the Santa Maria and Calchaqui, which unite near the town of San Carlos and form the river Guáchipas, drain a much broken Andean region lying between 24° and 26° 30′ S. in the Argentine province of Salta. Having received the Arias, the Guáchipas runs north-eastwards about 50m., and then it changes its name to the Juramento, which is retained until the river reaches the Chaco plains at the base of the foot-hills of the Andes. Here it becomes the Salado. It joins the Paraná near Sante Fé in 31° 39′ S. and 60° 41′ West. Explorers of the Salado, inclusive of Captain Page in 1855, claim that its lower half is navigable, but the many efforts which have been made to utilize it as a commercial route have all resulted in failure.

The Pilcomayo, the Bermejo and the Salado erode quantities of the Pampean material, dissolve it into silt and pour it into the Paraguay and Paraná rivers. The engineer, Pelleschi, estimates that "the soil annually subtracted from the territory of the Chaco by the Bermejo alone equals 6,400,000 cubic yards."

Lower Course of the Paraná.—From 31° 30′ south to the Plata estuary the western bank of the Paraná is a precipitous bluff of reddish clay, varying from 25 to 75ft. above mean river level. It is being gradually undermined, and tumbles into the water in great blocks, adding to the immense volume of silt which the river carries. The Paraná is lowest in December; it rises in January, February and March, reaching its greatest height in March. It is steady in April, May and June, but falls and rises irregularly during the next three months. The difference between low and high river is generally about 12ft., depending upon the varying quantity of rains in Brazil and the melting of the Andean snows. Below its junction with the Paraguay the Paraná has an average current of 2½m. an hour, and the river varies in width from 1 to 3m., at low water; but in floods it seems almost a continuous lake, broadening to 10 and 30m. and burying many of its numerous islands and marginal swamps under a vast sheet of water, and obliterating its many parallel lateral channels and connecting canals.

Islands of Paraná.—In the middle Paraná, from the mouth of the Iguazú to the mouth of the Paraguay river, there are many islands, some of them large, rocky and high above the river. From Paraguay to the city of Rosario, islands are numerous, many of them of great area; and again below Rosario they soon increase in number and size until the Plata estuary is reached. In flood-time the upper portion of the trees being out of water, they have the appearance of floating forests. Then the river often makes wild work with its banks, and builds up or sweeps away entire islands, leaving deep channels instead. The lower delta of the Paraná does not share in these phenomena; its islands and main channels appear more fixed. This probably is due to the less elevation attained by the waters in flood-time, and the numerous branches which distribute them into the Plata estuary. This must have extended, in a very recent geological period, inland from its present head to at least 32° S.; but the enormous quantity of silt which the Paraná receives from its Paraguay affluent, and from the tributaries which reach it from the Andes, has filled this length of about 220m. with these muddy islands, which rest upon a sandy bed of great depth.

Paraná Delta.—The frontage of the Paraná delta is 40m. across, almost in a straight line from north to south. Through this the river finds its way to the Plata by 11 outlets, large and small, the two principal ones being the Paraná-Guazú and the Paraná de las Palmas. The Paraná is navigable to the São Lourenço river by craft drawing 3ft. of water, and to within a few miles of Asunción, the capital of Paraguay, by vessels drawing 9ft. The city of Paraná may always be reached with a draught of 12 and Rosario with 15ft. of water.

The commercial development of the Plata basin promises to become gigantic. The Andes on the west, the interior of South America on the north, great rivers, and the Brazilian mountains on the east of the Plata basin are obstacles which compel the rich and varied products of at least 1,500,000sq.m. of fertile country to seek access to the ocean by a single avenue—the Plata estuary. (G. E. C.)

During the 20 years ending in 1928 many of the ports, cities and towns located on the Plata-Paraná-Paraguay river system have made marked progress. Millions of dollars have been spent in extending and improving shipping facilities by Montevideo, La Plata, Buenos Aires, Rosario—all of them ports of call for ocean-going steamships. Many of the smaller ports like Santa Fé, Paraná, Corrientes, Posadas and Asunción, have also improved their facilities, and have increased their exports of grain, hides, meat, quebracho wood and extract, maté and lumber.

Improved Communications.—The completion, in 1916, of a 37m. railway around the Falls of Guayra, on the Alto Paraná river, opened a new river and rail gateway to the heart of Brazil, the principal outward shipments being yerba-maté and dried beef. A new hotel at Iguazú River falls and a motor-car service from Puerto Aguirre to the falls, 10m. distant, provide modern accommodation, and, aided by better steamboat service on the Alto Paraná have brought more tourists to the cataracts. The Rondon, the Roosevelt (1913–14) and other expeditions of recent years; the colonization schemes of European and American companies in Paraguay and Bolivia; the completion of a Brazilian railway from São Paulo nearly to the Paraguay; petroleum investigations in eastern Bolivia; larger areas planted with cotton in Argentina and Paraguay have combined to arouse wider interest in the vast region watered by the Plata river system. On the Uruguay river the cities of Mercedes, Paysandú and Salto have new water systems, improved streets and extended sanitation. A packing plant at Fray Bentos has increased operations there. The Argentine Navigation company, the Lloyd Brazileiro and local steamboat lines operate La Plata services to Corumbá, Brazil, 1,800m. from the Atlantic. Ocean-going vessels ascend as far as Rosario and Santa Fé 200m and 300m. above Buenos Aires. Throughout the Plata region the gradual introduction of modern agricultural implements has increased output, and, consequently, river traffic.

Bibliography.—W. J. Holland, *To the River Plate and Back* (1913); G. Ross, *Argentine and Uruguay* (1916); A. Boerger, *Sieben la Plata-Jahre* (1921); *Review of the River Plate* (Buenos Aires, weekly). (W. A. R.; G. E. C.)

PLATAEA or **PLATAEAE,** an ancient Greek city of Boeotia, situated close under Mt. Cithaeron, near the passes leading from Peloponnesus and Attica to Thebes, and separated from the latter city's territory by the River Asopus. Though one of the smallest Boeotian towns, it stubbornly resisted the centralizing policy of Thebes. In 519 B.C. it invoked Sparta's help against its powerful neighbour, but was referred by king Cleomenes to Athens (for the date, *see* Grote's *History of Greece*, ed. 1907, p. 82, note 4). The Athenians secured Plataea's independence, and thus secured its enduring friendship. In 490 the Plataeans sent their full levy to the assistance of the Athenians at Marathon, and during the invasion of Xerxes they joined eagerly in the national defense. At Artemisium they volunteered to man several Athenian ships, and subsequently abandoned their town to be burnt by Xerxes. In 479 they fought against the Persians under Mardonius in the decisive battle which bears the name of the city. (For an account of the battle *see* Graeco-Persian Wars.) Their great victory was celebrated by annual sacrifices and a Festival of Liberation (*Eleutheria*) in every fourth year at Plataea, whose territory moreover was declared inviolate.

In spite of this guarantee Plataea was attacked by Thebes at the beginning of the Peloponnesian War (431) and formally besieged by the Peloponnesians (429–27). The garrison after capitulating was put to death, and the city razed by the Thebans. The remaining Plataeans received a qualified franchise in Athens, and in 421 were settled on the territory of Scione. Expelled by Lysander in 404 they returned to Athens, until in 387 Sparta restored them in their native town as a check upon Thebes. The city was again destroyed by Thebes in 373, and the inhabitants once more became citizens of Athens. Plataea was rebuilt by Philip and Alexander of Macedon, and during the rest of antiquity enjoyed a safe but obscure existence. It continued to flourish in Byzantine and Frankish times. The walls of the town, which at various periods occupied different portions of the triangular ledge on which it stood, remain partly visible. Recent excavations have discovered the Heraeum; but the temple of Athena the Warlike, built from the Persian spoils and adorned by the most famous artists, has not been identified.

Authorities.—Strabo p. 411; Pausanias ix. 1–4; Herodotus vi. 108, viii. 1, ix. 25–85; Plutarch, *Aristides,* 11–21; Thucydides ii. 1–16, 71–78, iii. 20–24, 52–68; Isocrates, *Plataicus;* G. B. Grundy, *The Topography of the Battle of Plataea* (London, 1894) and *Great Persian War* (London, 1901), ch. xi.; W. Woodhouse in *Journal of Hellenic Studies* (1898), pp. 33–59; H. B. Wright, *The Campaign of Plataea* (New Haven, 1904); R. W. Macan, *Herodotus,* vii.–ix. (London, 1908), appendix; W. M. Leake, *Travels in Northern Greece,* ch. xvi., pp. 323–367 (London, 1835); *Amer. Journ. of Archaeology,* 1890, pp. 445–475; 1891, pp. 390–405. (M. C.)

PLATE, the common name for the electrode from which the current flows through the vacuous space in a radio vacuum tube.

PLATEAU, JOSEPH ANTOINE FERDINAND (1801–1883), Belgian physicist, was born at Brussels on Oct. 14, 1801, and died on Sept. 15, 1883 at Ghent, where he had been professor of physics from 1835. The more original investigations of Plateau refer chiefly to physiological optics and molecular forces. We owe to him the "stroboscopic" method of studying the motion of a vibrating body, by looking at it through equidistant radial slits in a revolving disk. In 1843 Plateau became permanently blind. He published an analytical catalogue of memoirs from the earliest times to the end of the 18th century on his favourite theme of subjective visual phenomena. This blind man's investigations on molecular forces, embracing hundreds of novel experiments whose results he saw only with others' eyes, are described in his great work *Statique expérimentale et théorique des liquides soumis aux seules forces moléculaires* (2 vols., 1873).

PLATED WARE: *see* Sheffield Plate and Electro-Plated Ware.

PLATE GLASS: *see* Glass Manufacture.

PLATE GLASS INSURANCE: *see* Insurance, Miscellaneous.

PLATEN-HALLERMUND, AUGUST, Graf von (1796–1835), German poet and dramatist, was born on Oct. 24, 1796, at Ansbach, and entered the Bavarian life guards in 1814. He took part in the short campaign in France of 1815; he then obtained a long leave of absence, and after a tour in Switzerland and the Bavarian Alps, entered the University of Würzburg in 1818 as a student of philosophy and philology. In 1819 he removed to Erlangen, where he sat at the feet of F. W. J. von Schelling. As a result of his Oriental studies he published a little volume of poems—*Ghaselen* (1821), each consisting of from ten to twenty verses, in which he imitates the style of Rückert; *Lyrische Blätter* (1821); *Spiegel der Hafis* (1822); *Vermischte Schriften* (1822); and *Neue Ghaselen* (1823).

Though Platen was at first influenced by the school of Romanticism, and particularly by Spanish models, yet the plays written during his university life at Erlangen, *Der gläserne Pantoffel, Der Schatz des Rhampsinit, Berengar, Treue um Treue, Der Turm mit sieben Pforten,* show a clearness of plot and expression foreign to the Romantic style. His antagonism to Romanticism became more and more pronounced, and he attacked its extravagances in the witty "Aristophanic" comedies *Die verhängnisvolle Gabel* (1826) and *Der romantische Oedipus* (1828). In 1826 he visited Italy, which he henceforth made his home, living at Florence, Rome and Naples. *Der romantische Oedipus* earned for him the bitter enmity of Karl Immermann and Heinrich Heine, but he retained many staunch admirers, who delighted in the purity of the subject matter of his productions and their beauty of form and diction. In Naples were written his last drama *Die Liga von Cambrai* (1833) and the delightful epic fairy-tale *Die Abbassiden* (1830; 1834), besides numerous lyrical poems, odes and ballads. He died at Syracuse on Dec. 5, 1835. Platen's odes and sonnets, to which must be added his *Polenlieder* (1831), expressing his sympathy for the Poles in their rising against the rule of the Tsar, rank among the best classical poems of modern times.

Platen's *Gesammelte Werke* were first published in one volume in 1839, and have been frequently reprinted; a convenient edition is that edited by K. Goedeke in Cotta's *Bibliothek der Weltliteratur* (4 vols., 1882). His *Tagebuch* (1796–1825), was published in its entirety by G. von Laubmann and L. von Scheffler (2 vols., 1896–1900). *See* P. Besson, *Platen, étude biographique et littéraire* (1894); A. Fries, *Platen-Forschungen* (1903); E. Petzet, *Platens Verhältnis zur Romantik in sein italien Zeit* (1911); R. Schlösser, *August Graf von Platen. Ein Bild seines geistigen Entwicklungsganges und seines dichterischen Schaffens* (Munich, 1910–13).

PLATERESQUE, the earliest of the styles of Spanish Renaissance, so called, either because the Renaissance found its first popular Spanish expression in silverware (*platero*, silversmith), or because its rich and delicate ornament resembled silversmith work. It is characterized by the application to forms structurally simple, of extremely rich ornament, distantly based on Italian Renaissance forms, using pilasters, entablatures, carved rectangular panels, shallow niches, much heraldic ornament and rich pierced, scrolled cresting. Its courtyards, usually with two or more openings on the upper floor, above a single opening below, are famous for their decorated columns, sometimes simulating balusters, their bracketed capitals and their graceful delicacy. Owing to Moorish influence, there is a common tendency to carry the decoration around the door over the full height of the wall above. Decorative ironwork, as in the church *rejerias* (*q.v.*), or open metal screens, was highly developed. The style embraces, generally, the first half of the 16th century, but its decorative ideals influenced not only the classic period which followed, but the Baroque as well. Characteristic examples are the hospital of Santa Cruz, Toledo, by de Egaz (1504–16), the college at Alcalá de Henares, by Gumiel (1500–17), the university and Irish college at Salamanca, the Casa de las Conchas at Salamanca and the Infantada at Guadalajara. (*See* Renaissance Architecture.)

(T. F. H.)

PLATERSPIEL, Blaterpfeife, a mediaeval simplified bagpipe, consisting of an insufflation tube, a bladder and a chaunter; the double reed in its socket at the top of the chaunter being concealed within the bladder. In the platerspiel we recognize the early mediaeval chorus (*q.v.*) a word which in mediaeval Latin was frequently used also for the bagpipe, while in its later forms it was practically identical with the cromorne (*q.v.*).

PLATINUM, a very heavy steel-grey metal of great usefulness in the chemical and mechanical arts.

Platinum was probably known in the impure state from very early times, but because of its physical properties and especially its high melting point it was impossible to work it by any of the arts then known and it therefore remained as an unnamed substance. (Symbol Pt, atomic number 78, atomic weight 195·23.) It was probably the metal alluded to in the early part of the 16th century by Scaliger, who refers to a metal incapable of being fused obtained from the mines in Mexico and Darien. About the middle of the 18th century it was introduced into Europe in small quantities and attracted the notice of various chemists. Scheffer, in a paper read before the Stockholm Academy entitled "On white gold or the seventh metal, termed in Spanish platina del Pinto" (1752), showed that it was insoluble in nitric acid but soluble in aqua regia, was precipitated from its solutions by mercury, and was infusible at the highest temperature of the furnace. He also dealt with some of its alloys and discovered that it was fusible when mixed with arsenic. Platinum was melted by Macquer and Baumé in 1758 in the focus of a powerful burning glass. Count von Sickingen in 1772 prepared the metal in the form of foil and wire and showed that it was soluble in nitric acid when alloyed with a large quantity of silver. For the later history of platinum, its occurrence and separation from the other metals, *see* Platinum Metals and Ruthenium, Rhodium, Palladium, Osmium and Iridium.

Platinum in the massive state is a greyish-white metal having a specific gravity of 21·4 and is exceedingly malleable and ductile. It melts at about 1,755° C and volatilizes readily in the electric furnace. Its latent heat of fusion is 27·18 calories. It is a bad conductor of heat and electricity. When pure it is a soft metal and on this account is not suitable for some purposes, but on alloying it with iridium in small amounts the hardness is greatly increased. It is capable of being welded at a temperature near its melting point, but for easier working at a lower temperature gold is used as a solder in repairing damaged crucibles and other articles. It alloys easily with all the other metals of its own group, likewise with gold, silver and lead, but is scarcely acted upon by metallic mercury. It has been obtained in the crystalline condition by distillation in the electric furnace or by heating the fluoride to a red heat (Moissan). Spongy platinum is readily produced by ignition of the double chloride $(NH_4)_2PtCl_6$; it possesses a much greater surface area than the massive metal and hence is more active when employed in catalysis. Platinum black is best prepared by warming a solution of any of the chlorides or double chlorides of platinum in caustic alkali with alcohol or some similar reducing agent, or by dissolving the lead in nitric acid from a not very rich lead-platinum alloy. It has an enormous surface area and hence is the most usual form in which platinum is employed in catalytic reactions. The platinum black, for convenience in handling and also to minimize loss, is usually deposited upon some suitable material such as asbestos or barium sulphate. Colloidal platinum can be obtained in solution by passing an electric arc between platinum terminals under pure water.

Uses.—Platinum is used in the laboratory in the form of dishes, crucibles and weights, although a small amount of iridium is generally added to increase its hardness and hence its durability. Platinum vessels, however, should never be used for heating caustic alkalis, as they undergo corrosion producing platinates, and no metal of low melting-point should ever be heated in them. At one time platinum vessels were almost exclusively used in concentrating sulphuric acid (*q.v.*) made by the chamber process; this use has been abandoned as sulphuric acid made by the contact process is already concentrated, and the chamber acid is now concentrated in cheaper vessels.

Platinum is the best catalyst for the manufacture of sulphuric acid by the contact process; at a temperature below a red heat it is capable of causing the reaction $2SO_2+O_2=2SO_3$ to be nearly completed. The resulting SO_3 is dissolved in water till an acid of the required strength is obtained (*see* Sulphuric Acid). Its use for this purpose has been partly given up, as some cheaper catalysts such as the oxides of iron and chromium, although less efficient, have been found more economical. In this process platinum is always used as platinum black. The material to be platinized (asbestos, pumice, brick, barium sulphate, etc.) is dipped in a dilute solution of platinum chloride, dried and ignited, an enormous catalytic surface of platinum black being thus produced. Another large and rapidly extending use for platinum is in the catalytic production of nitric acid from ammonia by oxidation. A mixture of ammonia gas and air (or oxygen) in the right proportion is passed in a very rapid stream over a network of heated platinum gauze. Either ammonium nitrate or nitric acid can be produced according to the proportions of oxygen and ammonia in the reaction mixture. The reaction is exothermic, and by adjusting the rate of flow of the mixed gases the reaction temperature can be kept constant.

Platinum or, better, iridium-platinum alloy is the most suitable anode material for electrolysis of all kinds. It remains unattacked under practically all conditions, but owing to the initial expense, some form of carbon, especially Acheson graphite, is now generally used for this purpose. Two methods of measuring high temperatures depend upon the use of platinum; the first is the platinum resistance thermometer, which depends upon the change of resistance of a platinum coil with temperature when a constant current is passing through it; the second is the use of a platinum and rhodium-platinum thermocouple. By careful calibration either of these instruments is capable of giving a very exact measurement of high temperatures. As platinum is not oxidized by air at the temperature of the electric spark, it is very suitable in electro-technics for contact-points of magnetos and induction coils and the armatures of electric bells; it can also be used when caused to glow by the passage of an electric current as a heating-element; for some of these uses it has now been displaced by cheaper materials, one of the best being a chromium–nickel alloy known as nichrome.

Platinum is extensively used for some surgical instruments such as needles for hypodermic syringes, for the metal can be sterilized even in the flame of a match; it is also used in the incandescent state as an electric cautery. Unfortunately it cannot be hardened sufficiently to make a good cutting edge. In dentistry platinum was formerly used extensively for making dental plates, etc., as an alloy of 2 parts of silver to one of platinum possesses the same coefficient of expansion as the hard porcelain-like material of which artificial teeth are composed. Owing to the rise in the price of platinum, gold or gold alloys have now almost entirely displaced it for this purpose. The use of platinum in jewellery is considerable; during the World War palladium replaced it to a large extent and now an alloy called white gold, which consists chiefly of gold alloyed with a small quantity of either palladium or platinum, is largely displacing it. Another use for platinum is the production of photographic prints by the platinotype process. These prints are of great beauty owing to the variety of tones that can be thus produced, and have the advantage over silver prints of being absolutely permanent.

Platinum Compounds.—Platinum does not combine directly with oxygen at any temperature, although in the molten state it absorbs several times its volume of this gas, which, however, is released when the metal cools. Four oxides of platinum are obtainable by indirect methods, viz., PtO, Pt_3O_4, PtO_2 and PtO_3. Of these, PtO and PtO_2 are important as they are the bases of the platinous and platinic salts. *Platinous oxide,* PtO, is obtained by gentle ignition of the corresponding hydrate, $PtO{,}2H_2O$, which is obtainable by precipitating either $PtCl_2$ or K_2PtCl_4 with caustic alkali. It is a black powder, soluble in acids when freshly prepared. *Platinic oxide*, PtO_2, is known in the hydrated form $Pt(OH)_4$, but only a portion of the combined water can be removed before deeper decomposition begins to take place. The hydroxide is obtained by adding excess of caustic soda to a boiling solution of $PtCl_4$, which gives a yellow solution of sodium platinate, and then precipitating the cold solution with acetic acid. It is a white or yellowish solid soluble both in dilute acids and in alkalis when freshly prepared, but after losing water on heating it becomes black and insoluble. The peroxide, PtO_3, is obtainable by electrolyzing an alkaline solution of $Pt(OH)_4$ at 0° C. It is a red-brown unstable solid which readily parts with some of its oxygen at ordinary temperatures.

Two well-defined chlorides of platinum are known—platinous chloride, $PtCl_2$, and platinic chloride, $PtCl_4$. *Platinous chloride* is formed by heating chloroplatinic acid to 300° C or evaporating a solution of the same substance with absolute alcohol to dryness several times. It is a greenish or sometimes brownish substance insoluble in water but soluble in hydrochloric acid or alkali chloride solutions, with which it forms double chlorides of the form M_2PtCl_4; these are the alkali salts (platinochlorides) of chloroplatinous acid, H_2PtCl_4. This acid, which is known only in solution, can be obtained also from either its barium or silver salt by exact precipitation by means of sulphuric or hydrochloric acid respectively. The best known salt of the acid is the potassium compound, which is easily produced by reducing a boiling solution of potassium chloroplatinate with sulphur dioxide. It crystallizes in dark red prisms easily soluble in water, and in the case of certain unfortunate persons, traces of it act as a violent irritant to the mucous membrane of the eyes and nose. Platinous chloride combines with various unsaturated substances to form double compounds; it combines directly with carbonic oxide at 250° C to form three compounds, $PtCl_2{,}CO$; $(PtCl_2)_2{,}3CO$; and $PtCl_2{,}2CO$; with phosgene to form $PtCl_2{,}2COCl_2$; with ethylene to produce $PtCl_2{,}2C_2H_4$; and with phosphorus trichloride to form compounds $PtCl_2{,}PCl_3$ and $PtCl_2{,}2PCl_3$.

Platinic chloride, $PtCl_4$, is formed by the action of chlorine on platinum at a temperature below 500°. If platinum is dissolved in aqua regia or in hydrochloric acid in a stream of chlorine and the solution is evaporated with hydrochloric acid till free from nitric acid, reddish-brown crystals of chloroplatinic (platinichloric) acid, $H_2PtCl_6{,}6H_2O$, are produced: these if ignited in a stream of hydrogen chloride gas at 165° give a residue of $PtCl_4$ as a reddish-brown, very hygroscopic, crystalline mass. The pure chloride, however, is rarely met with, and the platinic chloride of commerce is the compound $H_2PtCl_6{,}2H_2O$ formed by heating the hexa-hydrated compound to 100° C. Chloroplatinic (platinichloric) acid is a weak acid, it reddens litmus paper and decomposes metallic carbonates producing the corresponding platinichlorides. It forms potassium and ammonium compounds which are nearly insoluble in water and quite insoluble in a mixture of alcohol and ether; the corresponding sodium compound is soluble in this mixture, and this circumstance affords the best method of separating potassium from sodium quantitatively. Chloroplatinic (platinichloric) acid forms compounds with organic bases which are usually difficultly soluble in water.

Platinum is not attacked by fluorine at a low temperature, and advantage of this was taken by Moissan when he first isolated that element and by Moissan and Dewar when they first liquefied this gas. At higher temperature (500°–600° C) Moissan obtained two fluorides, PtF_2 and PtF_4. Platinum does not readily form stable salts with oxy-acids. A sulphate $Pt(SO_4)_2$ is said to have been produced by dissolving platinic hydroxide in sulphuric acid but no nitrate of platinum is known. A series of salts known as platino-nitrites having the general formula $M_2Pt(NO_2)_4$ is well known, and another series, the platino-oxalates of the composition $M_2Pt(C_2O_4)_2$ has also been recorded. Two sulphides of platinum, PtS and PtS_2, are definitely known, and the existence of various intermediate ones has been announced from time to time. PtS and PtS_2 are produced by acting upon solutions of corresponding platinum compounds with sulphuretted hydrogen. Both sulphides are black powders; PtS_2 must be dried without access of air as it readily undergoes oxidation.

Platinous cyanide, $Pt(CN)_2$, is best produced by precipitating a solution of potassium platinochloride, K_2PtCl_4, with mercuric cyanide. It is of importance as it combines with cyanides of the alkali and alkaline-earth metals to produce a series of salts known as platinocyanides which are remarkable for their wonderful colours and for their use in radiography. They are derived from platinocyanic acid, $H_2Pt(CN)_4$, which can be prepared by decomposing the mercury or copper salt with sulphuretted hydrogen. The acid crystallizes from water in deliquescent prisms but is better crystallized from an ether–alcohol mixture. Potassium platinocyanide, $K_2Pt(CN)_4{,}3H_2O$, is easily produced by dissolving spongy platinum in a solution of potassium cyanide, preferably in the presence of air, or by the interaction of a solution of platinous chloride with excess of potassium cyanide; in the latter method recrystallization is necessary to remove the potassium chloride simultaneously produced. It crystallizes in rhombic prisms which are yellow by transmitted light but have a blue metallic lustre by reflected light. The magnesium salt, $MgPt(CN)_4{,}7H_2O$, crystallizes in beautiful red tetragonal prisms with metallic moss-green reflex. Its solution in water is colourless. Barium platinocyanide, $BaPt(CN)_4{,}4H_2O$, is the compound used for X-ray screens. It occurs in citron-yellow monoclinic prisms with a green reflex.

Platinum salts combine with ammonia in various proportions to form two series of bases, platinous and platinic ammines (*see* AMMINES). In the platinous series there are two compounds having the formula $PtCl_2{,}2NH_3$; they are probably cis- and trans-isomerides. A polymeride having the formula $(Pt{,}4NH_3)\ PtCl_4$ has long been known as the "green salt of Magnus," and is made by the action of ammonia upon platinous chloride. These compounds, although of great interest theoretically, are of little practical value. A complete account of these interesting compounds may be found in Gmelin-Kraut's *Handbuch.* (F. E. M.)

See L. Duparc and M. N. Tikhonovich, *Le Platine et les gîtes platanifères de l'Oural et du Monde* (1920); C. Janin, *World's Outlook for Platinum* (1928).

PLATINUM METALS. Although generally found in nature in the metallic condition, native platinum is never chemically pure. With it in varying proportions five other metals are generally associated, and to this group of six elements the name "platinum metals" has been given. The six metals in the order of their atomic numbers and weights are as follows:—

Metal	*Symbol*	*Atomic No.*	*Atomic Wt.*	*Metal*	*Symbol*	*Atomic No.*	*Atomic Wt.*
Ruthenium	Ru	44	101·7	Osmium	Os	76	190·8
Rhodium	Rh	45	102·91	Iridium	Ir	77	193·1
Palladium	Pd	46	106·7	Platinum	Pt	78	195·23

Although certain properties are common to the whole group, yet very great chemical and physical differences are found between the various members. It will be noticed that the atomic numbers of the first three and second three members are consecutive and that a common difference of 32 separates them. This common difference in atomic number corresponds to similarity in chemical properties between members differing by this constant number; at the same time similarities, more especially physical, are noticed amongst the members of each group.

One property common to the whole of the platinum metals is the high temperature of their melting points. The most easily fusible of them, palladium, only assumes the liquid condition at about 1,550° C; platinum comes next with a melting point of about 1,750° C and the other metals fuse at temperatures intermediate between these and the melting point of osmium, which is about 2,700° C. Another property common to this group of metals is the valuable one of resisting chemical action and especially oxidation (the particular cases of ruthenium and osmium as regards oxidation will be dealt with when those metals are considered in detail).

Another property common to all members of the group is their great catalytic action, that is, the power of bringing about chemical action between other substances without themselves undergoing any alteration. In small chemical operations platinum and palladium are extensively used, but for large-scale or commercial working these metals, on account of their high cost, are not suitable unless the wastage is very small or negligible. Thus platinum and palladium are most efficient catalysts in the hydrogenation of oils and fats for the production of edible glycerides (*q.v.*); they are, however, seldom used for this purpose since the inevitable wastage would cause the process to be too costly. Metallic nickel or certain of its compounds are used instead, with the result that the operation has to be carried out at a considerably higher temperature, resulting in the destruction of some of the important vitamins which would have survived had palladium been used instead of nickel.

As regards density or specific gravity, the platinum metals resolve themselves naturally into two groups: the three members of lowest atomic weight have specific gravities of 11–12, *i.e.*, somewhat higher than, but not far removed from, that of silver, 10–11; the three higher members, however, are much denser and their specific gravities range from 21·4 for platinum to 22·5 for osmium which is the heaviest massive substance known under terrestrial conditions. As the specific gravity of platinum is near to that of gold, 19·4, an alloy of platinum with some base metal is easily prepared possessing the same density as gold.

Being bad conductors of electricity, platinum and its allied metals in the form of wire easily become incandescent when an electric current is passed through them. Incandescent lamps with very luminous filaments for electric lighting could be made without any danger of fusing of these metals. The first practical success was attained with filaments of metallic osmium, which was found to glow more vigorously and thus give better illumination than the other platinum metals. This fact is perpetuated in the name "Osram" which is still a trade-mark of certain lamp manufacturers, although the use of osmium for this purpose has long been discontinued. Although the platinum filaments for lamps was soon displaced by tantalum and tungsten, yet for a considerable time platinum entered into their construction, as some material had to be used, which could be fused into the glass without cracking, to carry the necessary leading-in wires. The only suitable substance then known was platinum, which has a coefficient of expansion almost the same as that of glass, and for a considerable time this was the only available material. This wasteful use of platinum has now been obviated by the production of alloys of much cheaper material having the same coefficient of expansion as ordinary glass.

Occurrence.—The platinum metals appear to be widely distributed in nature, although generally in very small quantities. Localities in which they occur are Brazil, Colombia, Peru, Russia, Australia, Borneo, Tasmania, California and South Africa. Alluvial deposits have hitherto been the usual sources, but platiniferous reefs have now been found in the Transvaal and Natal. Alluvial platinum was reported in 1927 from Sierra Leone over an area of 40sq. miles. The first definite recognition of crude platinum as a separate metal occurs in the 18th century, when chemists obtained samples of platinum ore from Carthagena.

In 1803 and 1804 four new metals were obtained from platinum. Osmium and iridium were discovered and isolated by Smithson Tennant and palladium and rhodium by W. H. Wollaston. The remaining platinum metal, ruthenium, was not discovered till 1828 when Osann succeeded in isolating it from the platiniferous ore of the Ural mountains, a deposit discovered in 1819. The platinum ores obtained from various localities differ greatly in composition. Platinum is generally found as the chief metal and the other metals of the group occur in relatively small and variable quantities. Occasionally, however, and especially in Australia and South Africa, small nuggets or grains of osmiridium are found, and recently considerable amounts have been found in Tasmania which is now its chief source. This mineral consists chiefly of the metals osmium and iridium, and also usually of a certain amount of ruthenium, the other platinum metals occurring to a small extent only. In addition to the six platinum metals, platinum ores contain other elements, the most common being gold, copper, silver, iron, chromium and nickel.

Separation.—The methods in general use for the separation of the six platinum metals are here outlined, detailed accounts of their purification being shown under the headings of the several metals. A platinum ore which has been freed from base metals and other impurities is treated with aqua regia (*q.v.*); osmium, most of the iridium and a small amount of ruthenium remain undissolved. The solution, containing platinum, palladium, rhodium and small amounts of ruthenium and iridium, is evaporated to dryness, when the metals are obtained as chlorides. These chlorides are then heated to about 150° C whereby the chlorides of palladium and iridium are partly decomposed giving lower chlorides. The residual mass is dissolved in very dilute hydrochloric acid, and ammonium chloride is added to precipitate most of the platinum and iridium as double chlorides, the other metals remaining in solution. This solution is then treated with metallic iron (technically termed "footing"), which throws all the metals completely out of solution; this precipitate, like all others similarly obtained, is technically called "foots." The precipitate after thorough washing is again dissolved in aqua regia, the solution is concentrated and again treated with ammonium chloride to remove further amounts of platinum and iridium and then treated with ammonium hydrate, when nearly all the palladium is thrown out as a difficultly soluble ammine, $Pd(NH_3)_2Cl_2$. The solution now containing rhodium and ruthenium is evaporated to dryness and strongly ignited, leaving the metals themselves. These are fused with potassium bisulphate, when the rhodium forms a soluble double sulphate leaving the ruthenium unattacked.

The foregoing residues containing osmium, iridium and some ruthenium are heated in a tube in a stream of air or preferably oxygen. Osmium and ruthenium form volatile oxides which are deposited in the cold parts of the tube. The residue, iridium with some ruthenium and small amounts of other platinum metals, is purified by suitable methods. A method of treating crude platinum ores, particularly useful in concentrating the platiniferous portion, is to heat the ores with metallic lead or to make a mixture of the ores with galena, scrap iron, glass and borax, the last two materials serving as a flux. The platinum metals, except most of the osmiridium, are dissolved in the lead which is removed by ordinary cupellation, the platinum metals remaining ready for subsequent treatment. In modern reef-mining, the platiniferous ores are concentrated after grinding by methods of oil flotation.

Another method of opening up platinum ores is to treat a heated mixture of the substance and common salt with chlorine. All the platinum metals are attacked by this process giving double chlorides of the metal with sodium. As these double chlorides differ in stability, variations of the temperature of treatment give different products. Even if the double chloride is decomposed at or below the temperature of formation, the metal resulting from this decomposition remains in a finely divided condition and subsequent treatment is facilitated, and at the same time some of the stable double chlorides, especially that of iridium, are soluble in water and are easy to treat subsequently. It is obvious that with ores of different compositions some of the foregoing methods are more suitable than others in particular cases. Furthermore, all firms engaged in the refining of these metals have their own special secret methods. (F. E. M.)

Bibliography.—E. A. Smith, *Platinum Metals* (1925); A. D. Lumb, *The Platinum Metals* (1920).

PLATO (*c.* 428 B.C.–*c.* 348 B.C.), Greek philosopher, son of Ariston and Perictione, was born in the year 428–427 B.C. and died in 348–347 at the age of over 80. His family was, on both sides, one of the most distinguished of Athens. Ariston is said to have traced his descent through Codrus to the god Poseidon; on the mother's side, the family, that was related to Solon, goes back to Dropides, archon of the year 644 B.C. Perictione apparently married as her second husband her uncle Pyrilampes (*Parm.* 126 *C*) a prominent supporter of Pericles, and Plato was probably chiefly brought up in his house: Critias and Charmides, leading men among the extremists of the reactionary Terror of 404, were respectively cousin and brother of Perictione; both were old friends of Socrates, and through them Plato must have known the philosopher from boyhood.

His own early ambitions as he tells us in the seventh *Epistle* (324 *b.*–326 *b.*) were political. The reactionaries urged him to enter public life under their auspices—at the age of 24—but he wisely held back till their policy should declare itself. He was soon repelled by their violences, particularly by their attempt to implicate Socrates in the illegal execution of their victim Leon. He hoped better things from the restored democracy, but its condemnation of Socrates finally convinced him that there was no place for a man of conscience in active politics. Hermodorus, an immediate disciple, is the authority for the statement that, on the execution of Socrates in 399 B.C., Plato and other Socratic men took temporary refuge with Eucleides at Megara. The later *Lives* represent the next few years as spent in extensive travels in Greece, Egypt, Italy. Plato's own statement is only that he visited Italy and Sicily at the age of 40 and was disgusted by the gross sensuality of life there, but found a kindred spirit in Dion, brother-in-law of Dionysius I. of Syracuse.

The Academy.—About or soon after 387, Plato founded the Academy as an institute for the systematic pursuit of philosophical and scientific research. He presided over the society for the rest of his life, making it the recognized authority alike in mathematics and in jurisprudence. From the allusions of Aristotle we gather that Plato lectured without manuscript, and we know that "problems" were propounded for solution by the joint researches of students. On the political side there are traces of tension between the Academy and the rival school of Isocrates.

The one outstanding event in Plato's later life is his intervention in Syracusan politics. On the death of Dionysius I. in 367, Dion conceived the idea of bringing Plato to Syracuse as tutor to his successor, whose education had been neglected. Plato himself was not sanguine of results, but as both Dion and the philosopher-statesman Archytas of Tarentum thought the prospect promising, he felt bound in honour to risk the adventure. The project was by training Dionysius II. in severe science to fit him for the position of a constitutional king who might hold Carthaginian encroachment in Sicily at bay. The scheme was crushed by his natural jealousy of the stronger Dion, whom he drove into virtual banishment. Plato paid a second and longer visit to Syracuse in the year 361–360, in the hope of still effecting an accommodation, but failed, not without some personal danger. When Dion captured Syracuse by a coup-de-main in 357, Plato wrote him a short letter of congratulation and warning against his own lack of tact and graciousness. After the murder of Dion in 354 the philosopher drew up the important seventh and eighth *Epistles*, reviewing and justifying the policy of Dion and himself and making proposals, unsuccessfully, for a conciliation of Sicilian parties.

The prejudice which led students in the 19th century to discredit the *Epistles*, in spite of the favourable opinion of scholars such as Bentley, Cobet, Grote, Blass, E. Meyer, worked havoc with their accounts of Plato's life. It is safe to say that at present the authenticity of the two letters of chief biographical importance, VII. and VIII., is established. I. and perhaps XII. are admittedly unauthentic; on the rest opinion is divided. It seems to be inclining (rightly, as the present writer thinks), in favour of acceptance. The best recent account of the events in Sicily is in E. Meyer, *Geschichte des Altertums*, vol. 5.

To us Plato naturally is important primarily as the greatest of philosophical writers, but to himself the foundation and organization of the Academy must have appeared his chief "work." In the seventh Epistle he utters on his own account the same comparatively unfavourable verdict on written works, in contrast with the contact of living minds, as a vehicle of "philosophy," which he ascribes to Socrates in the *Phaedrus* (Ep. VII. 341 *b.–e.*, 344 *c.*). It can hardly be doubted that he regarded his dialogues as intended in the main to interest an educated outside world in the more serious and arduous labours of his "school."

All the most important mathematical work of the 4th century was done by friends or pupils of Plato. Theaetetus, the founder of solid geometry, was a member of the Academy, as were also the first students of the conic sections. Eudoxus of Cnidus, the author of the doctrine of proportion expounded in Euclid's *Elements*, inventor of the method of finding the areas and volumes of curvilinear figures by exhaustion, and propounder of the astronomical scheme of concentric spheres adopted and altered by Aristotle, removed his school from Cyzicus to Athens for the purpose of cooperation with Plato. Archytas, the inventor of mechanical science, was a friend and correspondent. The Academy is thus the connecting link between the mathematics of the 5th century Pythagoreans and those of the geometers and arithmeticians of Alexandria.

Science.—Nor were other sciences neglected. Speusippus, Plato's nephew and successor, was a voluminous writer on natural history; Aristotle's biological works have been shown to belong largely to the early period in his career immediately after Plato's death, before the breach between the younger philosopher and the Academy. The comic poets found matter for mirth in the attention of the school to botanical classification. The Academy was particularly active in jurisprudence and practical legislation. "Plato sent Aristonymus to the Arcadians, Phormion to Elis, Menedemus to Pyrrha. Eudoxus and Aristotle wrote laws for Cnidus and Stageirus.

"Alexander asked Xenocrates for advice about kingship; the man who was sent to Alexander by the Asiatic Greeks and did most to incite him to his war on the barbarians was Delius of Ephesus, an associate of Plato." (Plutarch, *against Colotes*, 1126 *c.–d.*) The creation of the Academy as a permanent society for the prosecution of both exact and humane sciences was, in fact, the first establishment of a University.

Socrates.—The most important formative influence to which Plato's mind was exposed in youth and early manhood was that of Socrates. But it does not appear that Plato, whose first ambitions were political, belonged to the innermost circle of the old man's intimates, or regarded himself as a "disciple." In *Ep.* VII. he is careful to speak of Socrates not as a "master" but as an older "friend" (ἑταῖρος) for whose character he had a profound respect, and has recorded his own absence (through indisposition) from the death-scene of the *Phaedo*. It would seem that his own vocation to philosophy only dawned on him afterwards, as he reflected on the moral to be learned from the treatment of Socrates by the democratic leaders. Aristotle incidentally ascribes to him an early familiarity with the Heracleitean Cratylus, a younger man than Socrates and apparently an admirer of the philosopher. This may be only Aristotle's inference from the existence of the dialogue

Cratylus. It is more important to remember Plato's connection with Pyrilampes and Critias. Pyrilampes was a Periclean politician, and Critias was known as a democrat until his moral balance was upset by the collapse of the Periclean system in 404. Early upbringing in a family of Periclean politics having connection with Solon may explain why Plato's own estimate of democracy in the *Politicus* and *Laws* is much less unfavourable than that which he ascribes to Socrates in the *Gorgias* and *Republic*.

Beyond this, we can say only that Plato in early life must have been exposed to the same influences as his contemporaries. His early experiences covered the disastrous years of the Decelean War, the shattering of the Athenian Empire and the fierce civil strife of reactionaries and democrats in the year of anarchy 404–403. He was too young to have known anything by experience of the imperial democracy of Pericles and Cleon, or of the full tide of the "sophistic" movement. It is not from memory that he depicts Protagoras or even Alcibiades, as they were in their great days.

The Works.—The canon and text of Plato appears to have been fixed by two scholars, Dercylides and Thrasylus, either shortly before or shortly after the Christian era. Thrasylus is uncertainly identified with a grammarian of the name who flourished in the reign of Augustus and was "heard" by Tiberius. By reckoning the *Epistles* as one item, the list was made to consist of 36 works, arranged in nine "tetralogies," or groups of four. (Aristophanes of Byzantium had already attempted an arrangement in "trilogies," or groups of three, which, however, he did not carry through.)

Textual Problems.—No genuine work of Plato has been lost, but there is a general agreement of modern scholars to reject a number of small items from the text. Their verdict may be said to have gone definitely against the following, *Alcibiades I., Alcibiades II.* (suspected by some even in ancient times), *Theages, Erastae, Clitophon, Hipparchus, Minos*. Most or all of these are probably early Academic work, and possibly not all later in date than Plato's death. Most, though not all, contemporary scholars also regard the *Epinomis*—in the present writer's opinion wrongly—as an appendix to the *Laws* added *de suo* by the mathematician Philippus of Opus, who is recorded by Diogenes Laertius (III. 37) to have transcribed the work for circulation. The *Greater Hippias* and *Menexenus* are still regarded as doubtful by some, though Aristotle used both, and expressly quotes the latter, in a way which seems to prove that he regarded them as Platonic. (The wild negative criticism of German scholars of the middle of the 19th century, which received its death-blow in 1867 from L. Campbell's proof of the genuineness of *Sophistes* and *Politicus*, is now universally recognized to have been an aberration.) Plato's will, preserved by Diogenes (III. 41–43), is pretty certainly authentic. Some of the 32 epigrams ascribed to him in the *Anthology*, may conceivably be genuine.[1]

Order of Dialogues.—Plato's literary career extended over the greater part of a long life. The *Apology* must have been written while the memory of Socrates' appearance before his judges was still fresh; the *Laws* is confessedly the work of an old man with a long experience of life behind him, and the state of its text fully bears out the tradition, preserved by Proclus, that its aged author never lived to give it final revision. Some half a century or more must have elapsed between Plato's last and his earliest composition.

This of itself would prove that Schleiermacher, with whom modern critical study of Plato begins, went astray in assuming that Plato started his career with a ready-made complete "system" to be disclosed. We must expect to find in his writings evidence of the development of his mind. But if we are to read the development aright we must have some trustworthy way of determining the order of the dialogues. Plato himself has only given us the scantiest indications of the order. He has linked the *Sophistes* and *Politicus* externally with the *Theaetetus* as professed continuations of the conversation reported in that dialogue; he has also, as most students recognize, linked up the *Timaeus* in the same way with the *Republic*. Aristotle adds one other piece of information, that the *Laws* were written after the *Republic*. Further investigation of the problem opens in 1867 with L. Campbell's edition of the *Sophistes* and *Politicus*, and the work thus begun was continued by others, notably W. Dittenberger, C. Ritter and W. Lutoslawski.

By consideration of numerous independent stylistic criteria (for which *see* the works named at the end of this article), it has been definitely established that the dialogues *Sophistes, Politicus, Philebus, Timaeus* (with its fragmentary sequel *Critias*), *Laws*, form a distinct linguistic group, which must belong to the later years of Plato's life, as we might have presumed from the consideration that Socrates, the central figure of other dialogues, becomes, in those of this group (with a solitary exception for the *Philebus*, the one member of the group which is wholly preoccupied with ethics), a secondary personage, and disappears altogether from the *Laws*. The whole group must therefore be later than the *Sophistes*, which professes to be a sequel to the *Theaetetus*. Now the *Theaetetus* can be dated with some accuracy, since it commemorates the recent death of the eminent mathematician after whom it is named from disease and injury contracted in a campaign before Corinth, which, as elaborately proved by Eva Sachs (*de Theaeteto Atheniensi*, Berlin, 1914), must be that of 369 B.C. The dialogue may thus be safely ascribed to 368–367, the eve of Plato's departure for Syracuse, and the marked change of style visible in the *Sophistes* is best explained by the supposition that there was a break in Plato's literary activity during the years 367–360 when he was specially occupied with Sicilian affairs. So much may be regarded as fairly certain.

The Earlier Dialogues.—It is not so easy to reach definite conclusions about the order of composition of the more numerous earlier group of dialogues. It is generally recognized, on linguistic and other grounds, that the series ends with the *Theaetetus* and the closely related *Parmenides*. Attempts have been made by C. Ritter, Lutoslawski and others, to determine the internal order of the group on linguistic evidence, but there are obvious reasons for doubting whether the methods which have been successful in establishing the distinction between the two great groups of earlier and later dialogues can be applied with the same confidence to works belonging to the same general period of their author's life and composed probably at no great distance of time from one another.

In point of fact, there is not complete agreement between the arrangements proposed by different "stylometrists," and their advocates have usually eked out the strictly philological argument by more or less dubious assumptions about the development of Plato's thought, though it is very questionable whether any real development can be traced before the *Theaetetus* and *Parmenides*.[2] Perhaps all that can be said with certainty is that the great outstanding dialogues, *Symposium, Phaedo, Republic* (and the writer of this article would be inclined to add *Protagoras*), in which Plato's dramatic power is at its highest, mark the culmination of this first period of literary activity. The comparative decline of dramatic power, accompanied by compensating maturity of critical acumen is the most striking contrast between the dialogues of the second and those of the first period.[3] A good account of the work done by the "stylometrists" will be found in H. Raeder, *Platons philosophische Entwickelung* (1905).

The Socrates of the Dialogues.—The great initial difficulty which besets the modern student of Platonic philosophy is that created by the dramatic form of Plato's writings. Since Plato never introduces himself into his own dialogues, he is not formally committed to anything which is taught in them. The speakers who are formally bound by the utterances of the dialogues are their protagonists, Socrates, Parmenides, the Pythagorean Timaeus, and all these are real historical persons. The question thus arises, with what right do we assume that Plato means us to accept as his own the doctrines put into the mouths of these characters? Is his purpose dogmatic and didactic, or may it be that it is mainly dramatic? Are we more at liberty to hold Plato responsible for what is said by his *dramatis personae* than we should be to treat a poet like Browning in the same fashion?

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[1] The most dubious are also the best known. That on Agathon (imitated by Shelley, "Kissing Helena") and that on Alexis and Phaedrus are condemned by the occurrence of the names Agathon and Phaedrus. They are obviously suggested by the parts played by the tragic poet Agathon and Phaedrus of Myrrhinus in the *Symposium* and *Phaedrus*. The author has forgotten that both were grown men in Plato's childhood. This suggests suspicion of all the "amatory" verses. The syntax of the first of the epigrams on Aster is also singular.

[2] *See* in particular the important study of P. Shorey, *The Unity of Plato's Thought* (1903).

[3] In *Ep.* VII. 326*a* Plato seems to refer to *Rep.* VI. 499 *b–c.* as already written before his first visit to Sicily in 387. It has been argued that the *Symposium* must be later than 385 since Aristophanes, who died in that year, is introduced into the dialogue. But it is not clear that Plato made it an absolute rule never to introduce living speakers. It is hard, *e.g.*, to believe that Eucleides must have died while the *Theaetetus* was being written.

It is tempting to evade this formidable issue in one of two ways. One is that of Grote, who held that Plato allows himself freely to develop in a dialogue any view which interests him for the moment, without pledging himself to its truth or considering its compatibility with other positions assumed elsewhere in his writings. Thus, according to this theory, Plato can make Socrates advocate hedonistic utilitarianism in the *Protagoras*, or denounce it in the *Gorgias*, can assert the so-called "ideal theory" through the mouth of Socrates in the *Phaedo*, or refute it in the character of Parmenides in the dialogue of that name, with equal gusto and without pledging himself in either case. His championships are purely dramatic, or, at most, reflect his passing mood at the moment of composition.

The more common assumption of the 19th century was that some of Plato's characters, notably Socrates and Timaeus, are "mouthpieces" through whom he inculcates tenets of his own, without concern for dramatic or historical propriety. Thus it was, and often still is, held that the most famous philosophical doctrines of the *Phaedo* and *Republic*, the "ideal theory," the doctrine of "recollection" and of the tripartite soul, were actually originated by Plato after the death of Socrates, to whom these speculations were entirely unknown, and consciously fathered on the older philosopher by a mystification too glaring to deceive any one seriously. Careful study of the dialogues should satisfy us that neither of these two extreme views is tenable.

The Thought of the Earlier and Later Dialogues.—There is undeniably a real difference between the thought of the dialogues which are later than the *Theaetetus* and those which are earlier, and this difference will have to be accounted for. But there are no serious discrepancies of doctrine between the individual dialogues of the same period.[1]

Now Plato seems to announce his own personal conviction of certain doctrines of the second group of dialogues by a striking dramatic device. In the *Sophistes* and *Politicus* the leading part is taken by an Eleatic and in the *Laws* by an Athenian who are the only anonymous, indeed almost certainly the only imaginary, personages in the whole of Plato's writings.[2] It can hardly be doubted that the reason why these two characters have been left anonymous is precisely that the writer may be free to use them as "mouth-pieces" for his own teaching. Plato thus takes on himself the responsibility for the logic and epistemology of the *Sophistes* and *Politicus* and the ethics and educational and political theory of the *Politicus* and *Laws* in a specially marked way, and by doing so compels us to face the question how far he means the utterances of Socrates in his earlier dialogues to be taken as expressions of a philosophy of his own.

"Forms."—It may be regarded as an established result of the inquiries of Dr. Henry Jackson and others that there is a definite philosophical doctrine running through the earlier dialogues which has as its main features the theory of "Forms" (the "ideal" theory), the theory that knowledge is "recollection," and the theory of the "tripartite soul." In the dialogues of the second period these tenets, as we have learned to know them from the earlier dialogues, appear only in the mouth of Timaeus, a 5th century Pythagorean older than Socrates, and the most important of them all, the theory of "Forms" is actually made the object of what looks like a refutation in the *Parmenides*.

The problem is to find an explanation of this puzzling fact. Are we, with Dr. Jackson[3] and others to distinguish two philosophies, both originated by Plato after the death of Socrates, an earlier and a later? Or are we to suppose that in the main the object of the first group of Plato's dialogues is to preserve the memory of Socrates and that the philosophy expounded is in the main what it professes to be, the thought of Socrates, coloured, no doubt, unconsciously but not consciously distorted, in its passage through the mind of Plato? On the second view we should have to say that, strictly speaking, Plato had no distinctive Platonic philosophy until a late period in his life, much as we can say that, though Kant was all through his life a prolific writer on philosophy, there was no distinctive Kantian philosophy before the *Critique of Pure Reason*. Most Platonic scholars are still unwilling to accept this interpretation of the facts, though there are weighty considerations which plead strongly for it.

Socrates and Plato.—It is significant that the only dialogue not earlier than the *Theaetetus* in which Socrates takes a leading part is the *Philebus*, the one member of the second group which deals exclusively with those ethical problems on which the thought of the historical Socrates had been specially concentrated. This is most naturally explained by supposing that Plato, from regard to fact, was unwilling to make Socrates the exponent of doctrines which he knew to be his own property, though it is hard to understand his misgivings if he had already for years been employing him in that very capacity.[4] (If, as is most probable, *Ep.* II. is authentic, the question would be definitely settled by the sentence of the latter [314 *c.*] "there is not, and never will be, a work of Plato; the works which now go by that name belong to Socrates embellished and rejuvenated.")

It is notable, too, that Aristotle apparently knew nothing of an earlier and a later version of Platonism. He attributes a definite doctrine to Plato which is quite unlike anything to be found in the first great group of dialogues, and seems to be known to him from oral communications in the Academy, though something like it can, by looking hard, be read between the lines in the *Philebus*. It was also the view of Neo-Platonic scholars like Proclus that the "ideal theory" expounded in the great earlier dialogues really originated with Socrates and that something of the same kind was also held by contemporary Pythagoreans in Italy (Proclus *in Parmenidem* ed. Stallbaum 562, 610), and the fact that Proclus does not find it necessary to argue the point seems to show that this had been the standing tradition of the Academy. Similarly Galen, in the early 3rd century of our era, has preserved the definite statement of the learned Stoic Poseidonius that the doctrine of the "tripartite soul," often said in modern times to be another invention of Plato's, is as old as Pythagoras (Galen *de placit. Hipp et Plat.* 425, 478).

Moreover, as Burnet has argued, it is very hard to believe that any writer would introduce a far-reaching novel speculation of his own to the world in the curious fashion which Plato is supposed to have adopted in the *Phaedo*, where Socrates is made to describe the "ideal theory" as something quite familiar which he has for years constantly canvassed with his intimates (nearly all, if not all, of whom, were certainly living when the *Phaedo* was circulated). It is not necessary here to determine the historical question. We may be content to turn to the Platonic dialogues, carefully distinguishing the successors of the *Theaetetus* from its predecessors, and attempt a summary of their contents. The general doctrine of the first period will be described without any more or less arbitrary attempt to say how much of it may be actually "Socratic." We may then consider how far this doctrine is modified in later dialogues, or in the version of Platonism presupposed by Aristotle's criticisms.

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[1] As there would be between the *Protagoras* and the *Gorgias* or *Phaedo* if the *Protagoras* really said that the pleasure is the good. What it actually says is only that "the many," "most men," hold this view (353 *d.-e.*), and ought not therefore to regard the doctrine that "goodness is knowledge" as paradoxical, since on their own theory, virtue will amount to right computation of pleasures and pains.

[2] Except the two minor personages of the *Laws*, a Spartan and a Cretan, who have really nothing to do except to say "Yes," "No," in the appropriate places.

[3] *Journal of Philology* X.-XII.

[4] It might be said that if the principal doctrines of the Platonic Socrates were known by Plato to be his own peculiar property, he might feel a difficulty about putting a new and more critical philosophy into the mouth of the speaker who had been used as the exponent of his "earlier" teaching. But this would not wholly explain why Socrates might not have been made to teach the logic of the *Sophistes*.

No attempt will be made here to describe the personality or temperament of Plato which is, in fact, as elusive as that of Shakespeare and for the same reason. He is often credited with a strongly "mystical" and "erotic" temperament. He does ascribe such a temperament to Socrates, but it is puerile to treat his picture of Socrates as evidence about himself, though the mistake is constantly committed.

It should therefore be noted that the "mysticism" is confined to dialogues of the first period, in which Socrates is its exponent, and that the "erotic" language in which Plato's Socrates speaks of his devotion to his young friends was also used by the Socrates of Aeschines to describe his relations with Alcibiades (Fr. 4, Krauss). There is no evidence that Plato personally ever fired the imagination of gifted boys as Socrates did. Apart from the *Epistles*, the most valuable light we possess on Plato's personality is afforded by Aristotle's description of him as a man "whom it is blasphemy in the base even to praise" (*ὃῖ οὐδ' αἰνεῖν τοῖσι κακᾶσι θέμις*).

THE EARLIER DIALOGUES

In the *Republic*, the greatest of all the dialogues which precede the *Theaetetus*, there may be said to be three main strands of argument deftly combined into a consummate artistic whole, the ethical and political, the aesthetic and "mystical," and the metaphysical. Other major dialogues belonging to this period give special prominence to some one of these three lines of thought; the *Phaedo* to the metaphysical theme, the *Protagoras* and *Gorgias* to the ethical and political, the *Symposium* and *Phaedrus* to the aesthetic and "mystical," though in none does Plato make an artificially rigid separation of any one of the great ideal interests of human life from the rest.

The shorter dialogues deal with more special problems, usually of an ethical character, and mostly conform to a common type. A problem in moral science, often that of the right definition of a "virtue," is propounded, a number of tentative solutions are considered and are all found to be vitiated by difficulties which we cannot dispel; we are thus left, at the end of the conversation, aware of our discreditable ignorance of the very things it is most imperative for man to know. We have formally "learned" nothing, but have been made alive to the worthlessness of what we had hitherto been content to take for knowledge and the need of seeking further enlightenment.

The effect of these "dialogues of search" is thus to put us in tune with the spirit of Socrates, who had said that the one respect in which he was wiser than other men was just his keen realization of his own ignorance of the most important matters. We learn the meaning of his ruling principle that the supreme business of life is to "tend" the soul (to "make it as good as possible") and his conviction that "goodness of soul" means first and foremost, *knowledge* of good and evil. The three dialogues directly concerned with the trial of Socrates have manifestly a further purpose. They are intended to explain to a puzzled public why Socrates thought it stuff of the conscience neither to withdraw from danger before trial, nor to make a conciliatory defence, nor, finally, to avail himself of the opportunity of flight after conviction. Even well-wishers like Xenophon, as we know, were puzzled by what had seemed his wilfully defiant attitude; it was therefore a debt of honour to his memory to put the matter in the true light. In the remarks which follow, we will consider these shorter dialogues in an order adopted simply for purposes of convenience.

Hippias I. and II.—In these dialogues Socrates has as "respondent" the well-known polymath Hippias of Elis, whose self-complacency is sharply satirized. In the *Hippias Maior* the question propounded is "What is the fine" (*καλόν*)? "Fine" is a predicate by which we are constantly expressing both aesthetic and moral approval; do we really know what we mean by it? We discover that we do not, though incidentally we also learn that "fine" or "beautiful" is certainly not a synonym for either "useful" or "pleasant." *Hippias Minor* deals directly with the famous Socratic paradox that "wrong-doing is involuntary." It is commonly held that it is much worse to tell a wilful untruth than to blunder into an unintentional false statement. Yet the analogy of the arts and professions seems to show that the man who errs intentionally, if there is such a person, is a better man than he who errs unintentionally. (The suggested thought, of course, is that there "is no such person." The man who knows what is good will always aim at this and at nothing else,—the familiar doctrine of Socrates.)

Ion, Menexenus.—Both these are "occasional" works. Socrates had said that he found the poets, who as a class are commonly reckoned "wise," quite unable to explain to him how they came to say their best things, or what they meant by them. (*Apol.* 22 *a.–c.*) The *Ion* develops this thought into the theory that neither the poet, nor his interpreter the "rhapsode," produces his effects "by science," *i.e.*, as a result of conscious "artistry"; the effect in both cases is due to a non-rational "inspiration," or, as we now say, "native genius." (The importance of this is that it rules out appeal to the poets as specially competent authorities on the conduct of life.)

The *Menexenus*, which professes to repeat a "funeral oration" learned from the famous Aspasia, is apparently meant as a satire on "patriotic" distortion of history. Apparently the "discourses" satirized are those of Pericles in Thucydides, Lysias (Lysias II.) and Isocrates (the Panegyricus). The singular anachronism by which Socrates (and Aspasia) are represented as commenting on the events of the Corinthian War down to the year 387 must be intentional, whatever its object.

Charmides, Laches, Lysis.—These are typical "dialogues of search." The question of the *Charmides*, which contains a particularly delightful picture of the way of Socrates with a promising lad, is what is meant by *sophrosyne*, the virtue which is shown alike in graceful and easy command of one's appetites and passions, in dutiful behaviour to parents, elders, official "superiors," in balance and sanity amid the ups and downs of fortune. We seem to be in a fair way to identify this virtue with "knowledge of self"—the self-knowledge Socrates had valued so highly—when we are confronted with an ambiguity. "Self-knowledge" might be taken to mean a knowledge which has knowledge itself for its object, in fact for "epistemology." But it is hard to be sure that there is any such science as "the knowledge of knowledge," and harder still to see how such knowledge could be directive of conduct.

In the *Laches* we are concerned with valour, the soldier's virtue. Here again we are on the point of defining the virtue as knowledge of what is and what is not really to be dreaded. But this is tantamount to saying the true knowledge of evil and good, and the resultant definition, "valour is knowledge of good" would identify valour with the whole "goodness of man." That is, the definition is only possible if we can meet the popular objections to the Socratic thesis of the "unity of virtue."

The *Lysis* examines in the same tentative way, friendship, the relation in which self-forgetting devotion most conspicuously displays itself. The *crux* of the problem is that after many false starts, we seem to have reached a promising result in the view that each friend is really "a part of" the other in "soul or temper or body," and yet it is hard to reconcile this position with the facts which seem to show that "unlikeness" is a potent source of attraction. Aristotle has taken up and discussed the issues raised in the dialogue in his own treatment of the same subject (*E.N.* VIII.–IX.).

Cratylus.—The question here, one much agitated in the age of Socrates, is whether names are significant by "nature" or "convention." Is there some special appropriateness of the sounds of names to the objects called by them, or is there no bond between the thing and its name but that of the "usage of the community"? The absurdity of attempts to get metaphysics out of etymologies is humorously exposed by showing that the method can be used at pleasure to prove either that the "giver of names" agreed with Heracleitus that motion is the sole reality or that he held, with Parmenides, that motion is an illusion. Yet there are real analogies between "vocal gestures" and the things signified by them, which are pointed out with a good deal of insight. The main purpose of Plato, however, is to dwell on the point that language manship means the promotion of national character as the one thing which matters, and is therefore simply the application, on the grand scale, of the principles of absolute morality; what falls short of this is opportunism masquerading as statesmanship.

These convictions clearly imply a far-reaching metaphysic as their foundation and justification. The principles of this metaphysic, though they are frequently hinted at in passages of dialogues already reviewed, are put before us more explicitly in those we have now to consider; in connection with them we shall also observe an explicit theory of knowledge and scientific method.

Phaedo.—The *Phaedo* is often treated as though its object were to provide a demonstration of the immortality of the soul. It does not really profess to do this. The object is to justify faith in immortality as a rational faith by showing that it follows naturally from a fundamental metaphysical doctrine (the "ideal theory" or "doctrine of Forms"), which seems to afford a rational clue to the structure of the universe, though it is expressly said at the end of the whole discussion that this doctrine itself still requires further examination. At the same time, it is made fully clear that the writer accepts this metaphysical doctrine, with the reservation just mentioned, and is passionately sincere in the faith in "personal immortality" which he brings into connection with it. To be strictly accurate, indeed, we ought to say that the faith to be defended goes beyond belief in "immortality." What is being maintained is the "divinity" of the soul; its survival of death is a consequence of this inherent divinity.[1]

The argument is briefly as follows. A true philosopher may naturally look forward to death without dismay. For death is the separation of soul from body, and the philosopher's whole life has been spent in trying to liberate the soul from dependence on her body. In life, the body is always interfering with the soul's activity. Its appetites and passion interrupt our pursuit of wisdom and goodness; its infirmities are perpetually hindering our thinking. Even in our scientific work, we only attain exact and certain truth in proportion as we detach ourselves from reliance on sense-perception and learn to depend on pure thinking.

Death, then, only completes a liberation which the philosopher has been "rehearsing" all through life—if, that is, the soul continues to exist after death, as there are reasons for thinking. For:

I. There is a belief that the soul has a succession of many lives, and that when it is born into this world, it has come back from another. And there are two considerations to be urged on behalf of this belief. (*a*) The processes of nature in general are cyclical. The hot becomes cold, the cold hot; the waking go to sleep, the sleeping wake. It is reasonable to suppose that this applies to the case of dying and coming to life, so that the dead return to life, just as the living die. If this were not so, if the process of dying were not reversible, life would ultimately vanish from the universe. And (*b*) we may appeal to the doctrine that what we call "learning" is really "recollection," "being reminded" of something. This certainly seems to be the case, for in all our science we are perpetually being "put in mind of" precise ideal standards, mathematical or moral. We reason about exact quality, absolute justice and the like. Sense or experience never presents us with such perfect equality or justice; it only suggests them or "reminds us of them." We must therefore have become acquainted with them before we were confined to our bodies, and therefore must have existed before our birth. Now (*a*) and (*b*) together would prove what we want to prove, the soul's survival of death, though our "dread of the dark" makes us demand a more convincing argument.

II. We may consider the antithesis between the divine and eternal and the temporal and mutable, which runs through the universe. The body is certainly temporal and mutable. The soul is relatively immutable, like the fixed ideal standards or norms which she contemplates in her scientific thinking. Her thought is concerned with eternal objects and she herself has the likeness of that which she contemplates. If, then, some constituents of the body are nearly indestructible how much more should one expect the divine element in us, the soul, to resist destruction, as the traditions about re-birth assert that it does.

There are two grave "scientific" difficulties still to face. It may be argued: (*a*) that the soul is an "epiphenomenon," the "tune" (*ἁρμονία*) given out by the body, and if so, its superior "divinity" will not protect it from vanishing when the instrument which makes the music is broken; (*b*) that though the soul actually makes its own body, and perhaps can make a long succession of bodies, it cannot do so without "expending energy"; a time will come when it can no longer make a fresh body, and then it will itself disappear. We must not be driven into misology, antipathy to science, by this apparent clash between science and a faith to which we are attached.

The answer to (*a*) is that there are good souls and bad ones, and the good soul is "more in tune" than the bad one. But that which can be more or less "in tune" is clearly not itself a "tune." And if the soul were the "tune" resulting from the functioning of the body, its character at any moment would be a resultant of the condition of the body. How then could we have the experience, characteristic of the moral life, of the conflict between the soul with its aspirations and the body with its carnalities? The answer to (*b*) can only be given as part of a whole theory of the causes of "coming into being and passing out of being." Socrates had been led, early in life, to frame a tentative theory of the matter in consequence of his dissatisfaction with the chaotic state of physical speculation, and in particular with the failure of Anaxagoras to make any satisfactory use of his apparently teleological principle that "mind is the cause of all order and structure." He fell back on the method of "hypothesis."

What distinguishes this method from all others is that it begins by making an undemonstrated "postulate" (*ὑπόθεσις*). It then proceeds from this point to consider the truth or falsehood of the consequences which follow logically, from the initial postulate; the question of the truth of the postulate is, for the present, left unasked. Socrates' own fundamental unproved postulate has always been that usually, but loosely, called the "theory of Ideas." The postulate is that there really is a single determinate and immutable something (*εἶδος, ἰδέα*) answering to every significant "general term," and apprehended only by pure thought. The sensible things of which we predicate general terms temporarily "partake in" or "communicate with" the Idea or Form (*ἰδέα, εἶδος*). When we say that a thing becomes *e.g.*, beautiful, what we mean is that the Form (*ἰδέα*) "beauty" begins to be "present to" that thing, the thing begins to "partake of" the Form. When we say that a thing ceases to be beautiful, we mean that this relation of "presence," "participation," "communication" (*παρουσία, μέθεξις, κοινωνία*) is dissolved. This is the true account of the cause of "coming into and passing out of being," and if we accept it, we may proceed to our final argument for immortality.

III. There are Forms which are mutually incompatible, such as warmth and cold. Heat is never cool, and cold is never warm. But there are also certain sensible things of which it is an essential character to "partake of" a given Form. Such things will never admit an incompatible Form. Thus it is an essential character of snow to "partake of" cold. It will never, therefore, "partake of" the Form "heat." Similarly it is an essential character of a soul to be alive, to "partake of" the Form "life." It refuses to "partake of" the Form "death." At the approach of death, the soul must either retire or be annihilated (the metaphors are military). What we have said of its divinity forbids us to think that it is annihilated; we must therefore assume that it "retires" to some other region. The proof of immortality is thus hypothetical; it is shown to be involved as a consequence by the doctrine of Forms. This doctrine has been stated as a fundamental unproved postulate and it is admitted that it demands fuller consideration.

But our enquiry has at least satisfied us that the hope of immor-

[1] Plato's belief in immortality ought never to have been disputed. It is re-affirmed in the most unqualified way in the seventh *Epistle* (335*a–b*) and his very latest work, the *Laws* (904*c*–905*d*), though the particular arguments of the *Phaedo* do not re-appear there. Aristotle, too, in his early days as a member of the Academy, had taught the doctrine in his *Eudemus* (*Fragmenta,* ed. Rose 37–48). This consideration is really decisive. The characteristic argument of the *Law,* from the "self-moving" nature of the soul had already been used in the *Phaedrus* (245*c*). *Timaeus* 41*a*, where the final appeal is to the goodness of the Creator, formally applies not to men but to the stars.

tality is a reasonable one. (To distrust it would be to call the foundation of our whole philosophy into question.) The discourse ends with an imaginative cosmological myth depicting the future of the just and the unjust respectively.

In this statement of the theory of Forms (ἰδέαι, εἴδη) we may note the following points: (1) The doctrine is a piece of "realist" metaphysics. It is assumed that a universally predicated "general term" denotes or stands for an individual reality, apprehensible by thought, though not by sense. (2) There are a plurality of such Forms, standing in various logical relations with one another; whether they constitute a system with a definite structure the *Phaedo* does not tell us. (3) They are at once the objects known in all genuine science and the formal causes of all the temporal processes of the sensible world. (4) The sensible things which have the same names as Forms are said to owe their character to their "participation" (μέθεξις) of the Forms, or, equivalently, to the "presence" (παρουσία) or "communication" of the Forms to them. The precise character of this relation of "participation" is admitted to need further explanation. So far as the language of the *Phaedo* goes, a sensible thing would seem to be thought of as a temporary "complex" or meeting-place of universal characters and as nothing more.

Symposium, Phaedrus.—It is by no means clear that these two dialogues are closely connected in point of date, but they may be considered together as both presenting the Forms in a special light, as objects of mystical contemplation and excitant of mystical emotion.

The argument of the *Symposium* cannot be reproduced here as a whole. The immediate object of the dialogue, which professes to record the discourses made in eulogy of Eros by a group of eminent speakers at a banquet in honour of the tragic poet Agathon, in the year 416–5, is to find the highest manifestation of the "Love" which controls the world in the mystic aspiration after union with the eternal and super-cosmic Beauty, to depict Socrates as the type of the aspirant who has reached the goal of "union," and to set in sharp opposition to him the figure of Alcibiades, who has sold his spiritual birthright for the pleasures and ambitions of the world. The centre of philosophical interest lies in the discourse of Socrates, which he professes to have learned a quarter of a century ago from the priestess Diotima of Mantineia.[1]

The main argument may be summarized thus. Eros, *desirous* love, in all its forms, is a reaching out of the soul to a good to which it aspires but has it not yet in possession. The desirous soul is not yet in fruition of good. It is on the way to fruition, just as the "philosopher" is not yet in possession of wisdom but is reaching out after it.

The object which awakens this desirous love in all its forms is Beauty, and Beauty is eternal. In its crudest form, love for a beautiful person is really a passion to beget offspring by that person and so to attain, by the perpetuation of one's stock, the *succedaneum* for immortality which is all the body can achieve. A more spiritual form of the same craving for eternity is the aspiration to win immortal fame by combining with a kindred soul to give birth to sound institutions and rules of life. Still more spiritual is the endeavour, in association with chosen minds, to enrich philosophy and science with "noble discourses and thoughts."

But the goal still lies far ahead. When a man has followed the pilgrimage so far, he "suddenly descries" a Supreme Beauty which is the cause and source of all the beauties he has discerned so far. The true achievement of immortality is finally effected only by union with this. The philosopher's path thus culminates in a supreme "beatific vision." It is clear that the object of this vision, the "Beauty sole and eternal" of the dialogue, means what the *Republic* calls "the Good" or "Form of Good," which by its presence actually causes the goodness of everything else to which the name of good can be given. The Forms are thus thought of as a hierarchy with a supreme Form at their head, though no attempt is made at a rational theory of the way in which the supreme Form unites the rest into the system.

The immediate subject of the *Phaedrus* is the principles of "rhetoric" or, as we should say, prose composition. The *Gorgias* had told us that "rhetoric" as commonly practised is not a matter of rational principles at all, but a mere empirical trick of adapting one's tone to the prejudices of an audience. The *Phaedrus* aims at showing how a really scientific "rhetoric" might be built on the double foundation of logical method and scientific study of human passions. Plato contrives, however, by making a real or supposed "erotic" composition of Lysias the starting-point of his criticisms, to unite with this topic a discussion of the psychology of "love," and this, as in the *Symposium*, leads him to speak of the Forms as the objects of transcendental emotion. The soul is immortal, because it has within itself a native source of spontaneous movement.[2] In its disembodied state it shared the life of the gods and could enjoy the direct contemplation of "unbodied" reality, that is, of the Forms. It has suffered an antenatal fall into an embodied condition in which it is blind to everything which does not come in at the avenues of sense.

Now our senses only suggest few and faint images of such Forms as Justice and Temperance, but they can suggest Beauty in a much more impressive and startling way. To "fall in love" is to come under the influence of such sudden and arresting suggestions of Beauty; the "unreason" and "madness" of the lover mean that he is being awakened to realities which other men ignore. The "wings" of his soul are beginning to grow again, and his experience, rightly used, will be the first step in the soul's return to its high estate. This section of the *Phaedrus* is the *locus classicus* in Plato for the Forms as objects of mystical contemplation.

Republic.—The philosophy pre-supposed in all these dialogues receives its fullest exposition in the *Republic*. Here the immediate problem is strictly ethical. What is Justice (τὸ δίκαιον, δικαιοσύνη)? Can it be shown that Justice is always a boon, injustice a curse, to its possessor, apart from all consideration of consequences in this life or another? That is, is there a rational principle at the root of moral distinctions, and does the principle carry with itself its own intrinsic and indefeasible authority?

Plato's answer is that there is such a principle; each of us, in virtue of his special endowments and aptitudes, has a specific "work" or "vocation"; there is some special contribution which he, and no other, can make most effectively to the life of a rational society. Morality, "Justice," is to discharge that vocation to the height and with a single mind (τὰ αὐτοῦ πράττειν καὶ μὴ πολυπραγμονεῖν). To live thus is to be in spiritual health; to live otherwise is to be spiritually diseased. The obligation is thus intrinsic and absolute. This position has to be made good against the incoherencies of a morality of uncriticized traditional maxims, as well as against the "immoralism" of advanced thought (represented by Thrasymachus in Bk. I., expounded more intelligently by Glaucon in Bk. II.).

This leads us to consider what would be the general type of life in a society where the principle of Justice had power as well as manifest authority, and how it might acquire that power. Hence the need for a sketch (II., III.) of the institutions of the reformed society, and particularly of its moral and religious education. We have next to satisfy ourselves that the principles which regulate the public life of the morally healthy society are also recognizably the principles of the great virtues of private life. For this purpose, we need a psychology of voluntary action which is provided (Bk. IV.) by the doctrine of the "tripartite soul." This is not, indeed, a scientific psychology, but proves adequate to describe the moral life of the ordinary good citizen of such a society as we have conceived. The foundation of all this moral excellence is thus laid in absolute loyalty to a sound moral tradition enforced by education. To ensure that the tradition shall be thoroughly sound, we must stipulate that the authorities who create it do not themselves depend on tradition for their convictions about good and evil: they must not "opine," but know, by personal insight. The statesmen at the head of the community must be "philosophers" as well as kings (Bk. VI.).

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[1] It is important to remember that Socrates professes to be repeating a lesson he had learned at about the age of 30. This explains at once the words of *Symposium* 210*a*, where Diotima expresses uncertainty about Socrates' achievement of the complete "vision." He has his life yet to live; what it will be is not revealed. That the words have gravely been interpreted as a claim on Plato's part to have transcended his Master's limitations is only one example of the perversity with which he has been misunderstood.

[2] This is the argument for immortality to which Plato trusts in the *Laws*. It is not specially mentioned in the *Phaedo*, but this can hardly mean that Plato had not yet discovered it, since it is, in fact, taken from Alcmaeon of Crotona, a medical man of the beginning of the fifth century.

But the vision of "the Good" will only dawn on them if they have been prepared for it by an intellectual discipline in hard thinking which leads them through the curriculum of the exact sciences to the critical study of the metaphysical principles involved in science (Bk. VII.). The central books of the *Republic* thus present us with an outline of metaphysics and a philosophy of the sciences. We now turn back to consider the various stages of degeneration through which national and personal character pass when the true moral ideal is allowed to fall more and more completely out of view. As we pass them in review, we are increasingly confirmed in our conviction that, in respect of happiness, the life of regard for right is immeasurably superior to that of sating one's cupidities or gratifying one's personal ambitions (VIII.–IX.), and this conclusion is finally clinched (X.) by re-affirmation of the immortality of the soul. Since the soul is immortal, the issue which hangs upon our choice to live well or ill is one of infinite moment (X.).

The ethical scheme of the *Republic*, like that of the *Gorgias* and *Phaedo*, is dominated by the conception of the "three lives," ascribed by credible tradition to Pythagoras. The "lives" are those of the philosopher, the "man of action" (*φιλότιμος*), the votary of enjoyment (*φιλήδονος, φιλοσώματος, φιλοχρήματος*). The end of the first is wisdom, of the second, distinction, of the third, the gratifications of "appetite." Distinction is a worthier end in life than mere satisfaction of appetite; the supremely worthy end is wisdom. In a well-lived life, then, the attainment of wisdom will be the paramount end, and ambition and appetite will only be allowed such gratification as is compatible with loyalty to the pursuit of that paramount end. The psychological foundation of this doctrine is the theory of the "tripartite" soul, expounded fully in *Rep.* IV. Analysis of familiar experience reveals three "elements" (*μόρια, εἴδη*) or "active principles" within us, (1) considered rational judgment of good (*τὸ λογιστικόν*); (2) a multitude of clamant appetites for particular gratifications, which may be in violent conflict with our own considered judgment of good (*τὸ ἐπιθυμητικόν*); (3) a factor of "spirit," higher "ideal emotion," which manifests itself as "resentment" against both the infringement of our just rights by others and the rebellion of our own appetites against our judgment (*τὸ θυμοειδές*).

The same distinctions reappear in the structure of society. A society naturally falls into three divisions, the statesmen, who direct the public life, the general civilian population, who carry on the business of providing for material needs, and the executive force (army and police), whose function is, in a rightly ordered society, to give effect to the counsels of the statesmen by repressing attacks from without and rebellion from within.

These three "orders" are thus respectively, the judgment, the "appetitive" and "spirited" elements in the national soul. On this basis, we can proceed to work out an ethical and political theory. In ethics we can define the great leading types of "goodness," the quadrilateral, later known as the four "cardinal" virtues. *Wisdom* is the "excellence" of the "thinking part," clear and assured knowledge of the good; *courage*, the fighting man's virtue, is the "excellence" of the "spirited" part, unswerving loyalty, unshaken by pain, by danger, by the seductions of pleasure, to the rule of life laid down by judgment; *temperance*, the special excellence of the "appetitive" part, is the contented acquiescence of the non-rational elements in the soul in the plan of life prescribed by judgment; *justice* is just the state in which each of the elements is vigorously executing its own function and confining itself within the limits of that function. In the rightly ordered society, the national wisdom has the statesmen as its organ, the national courage the executive force; the national temperance is shown in the loyal contentment of each class in the community with its prescribed place and its duties.

Such a society is a true aristocracy, or rule of the best; "timocracy" the military state, in the better sense of that phrase, arises when the mere "man of action," only competent to fill the part of a good soldier, takes the place which rightly belongs to the thinker as directing statesman; "oligarchy" (*i.e.*, the dominance of "merchant princes," plutocracy), is a further deviation from the ideal, which arises when political power is bestowed on property as such. A still worse system is democracy, in which no attempt is made to connect political power with any special qualifications. Worst of all is tyranny, exercise of irresponsible power by the positively disqualified, the man of "criminal" will. The psychological scheme on which this construction is based is not given by Plato as a piece of strict science. We are carefully warned that exact truth is not to be reached by such an analysis of *prima facie* facts of social life (435 *d.*), and reminded later on that this apparent triplicity of the soul may prove to be only a temporary consequence of its conjunction with the body (611 *b.*).[1] The "tripartite" psychology, it is meant, enables us to give an account of the moral life, as it actually appears in a good citizen, which will fairly describe the facts. It is good popular psychology, useful for the moralist, but it is no more.

Hence it is improbable that the analysis originated with Plato himself. More probably it was, as the Stoic Poseidonius asserted, a piece of earlier Pythagorean doctrine, as is also suggested by the constant recurrence, throughout the section of the *Republic* in which the analysis is offered, of analogies from the specially Pythagorean science of Harmonics, and by the fact that the same doctrine is taught by the Pythagorean speaker in the *Timaeus*. Plato has, however, worked the theory into his ethics so completely that through him it has actually become a part of the psychology of Thomism, where it has to be squared, not quite satisfactorily, with the radically divergent psychological scheme of Aristotle.

In point of fact, the tripartite *schema* proves inadequate in the *Republic* itself when we advance in Bk. VI. to the consideration of the moral life of the "philosopher-king," whose "virtue" is founded on a personal *knowledge* of good. A higher level of moral goodness is demanded of him than of other citizens even of the ideal Utopia; his courage, for example, is declared to be no mere loyalty to right opinions inculcated by early education, but a high serenity arising from the knowledge of the relative insignificance of a brief individual life in the great universe which lies open to his contemplation. This has an important bearing on the teaching of the *Republic* about the unity of virtue.

In the ideal State itself, virtue does not appear as a complete unity. The leading types of moral excellence receive their several definitions. It is recognized that a special demand may be made on a particular section of the society in respect of a particular virtue of which it is, so to say, the public organ, as the fighting force is of the valour of the whole society. This is because, even in the ideal state, the moral convictions of citizens, other than the men of superlative intelligence and character who become "kings," are not supposed to arise from personal insight. They rest on opinions implanted by education, and are thus taken on trust. The good civilian or soldier, after all, is not living by a knowledge which is his own. But the rulers, by whose knowledge the rest of the community lives, must not, of course, themselves take their convictions on trust. They must know with a personal knowledge. The foundation of their virtue must be *insight* into a system of absolute values embodied in the very structure of the universe. In virtue of this deeper foundation the virtues in them are, so to say, transubstantiated and can no longer be distinguished from one another. They will fuse in knowledge of the good, as, in the Christian saints, they are fused in knowledge and love of God. It is in this form that the Socratic doctrine, "all virtue is one thing, knowledge" reappears in the *Republic* as the foundation of a society in which mankind has at last "escaped from its wretchedness," because knowledge rules.

In the *Republic*, as in the *Phaedo*, the Forms (*ἰδέαι, εἴδη*) appear in the double character of objects of all genuine science and formal causes of the world of events and processes. It is expressly denied that there can be knowledge, in the proper sense of the word, of the temporal and mutable. In the scheme laid down for the intellectual training of the philosophic rulers, ten years, from the age of 20 to that of 30, are assigned for systematic study of the exact sciences in the order: arithmetic, plane geometry, solid geometry, astronomy and harmonics. Special stress is laid on the points that the object of these studies is not practical applications but the familiarizing of the mind with relations between terms which can only be apprehended by thought, and that diagrams and models are to be treated merely as incidental aids to imagination. Five years are then further to be given to the still severer study which Plato calls "dialectic," a study which avails itself of no sensible aids to imagination. It proceeds "by means of Forms, through Forms, to Forms" (511 *b.*). It is, in fact, what we should call a critical metaphysic of the sciences. It examines the *ὑποθέσεις* or unproved postulates, of the various sciences, and its object is to "destroy" their character as unproved ultimate postulates (*τὰς ὑποθέσεις ἀναιροῦσα* 533 *c*) by discovering some still more ultimate really self-evident principle (an *ἀνυπόθετον*, 511 *b*) from which they follow as consequences.

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[1] Timaeus is expressly made to teach that the *θυμοειδές* and *ἐπιθυμητικό* are a "mortal element" (*θνητόν εἶδος*) added to the immortal soul to fit it for its habitation in the body (*Tim.* 69*c.*).

There can be no doubt that this most ultimate principle which is more than a "postulate" means the Good or Form of Good (*ἰδέα τἀγαθοῦ*) which is said to be the source at once of the reality and the knowability of all that is real and knowable, though it is itself neither knowledge nor being, but transcendent of both. (509 *b.*). On the methodological side the *Republic* thus completes the teaching of the *Phaedo* by providing the answer to the question then left open, when a "postulate" (*ὑπόθεσις*) may be regarded as finally established. It may be so regarded when it is seen to follow itself from the Good, which is the principle at once of existence and of value.

Socrates is made to confess (506 *d-e*) that he can give no positive account of this supreme metaphysical principle; he can only indicate its nature by an analogy. It is to the whole system of Forms what the sun is to the system of visible things, the source at once of their existence and of the light by which they are apprehended. The Good is thus thought of, to use scholastic terminology, as a transcendent reality which can be apprehended but never fully comprehended. The comparison with the sun and the free employment of the metaphor of "vision" indicate that the thought of the *Republic* is here the same as that of the *Symposium;* the Good is no other than the supreme Beauty which was there said to dawn suddenly upon the pilgrim of "Love" as he draws near to the goal of the journey. R. L. Nettleship rightly says that it holds the place taken in later philosophies by God, when God is thought of as the "Light of the world." But it would be deforming Plato's thought to call the Good of the *Republic* "God." The *Republic* is permeated by religious faith, but Theism as a principle of metaphysical explanation only makes its appearance in Plato's latest dialogues, and there as the solution of a problem which can hardly be said to have been adequately faced in the dialogues so far considered.

How the Good gives systematic structure to the plurality of Forms, the *Republic* does not tell us.

Development of the Doctrine of Forms.—So far we have been presented with a body of thought which has remained recognizably the same without serious modification throughout its various expositions. When we come to the two works which there is reason to regard as directly preluding to the dialogues of Plato's old age, the *Parmenides* and *Theaetetus,* we are struck by a remarkable difference of tone. With Plato, as with Kant, the "middle years" of life were clearly a period of fruitful critical reconstruction. There is an obvious motive for each reconstruction suggested by the *Phaedo* and *Republic* themselves.

The theory there expounded does not allow enough reality to the sensible world. It is quite false to say that even the *Phaedo* teaches an "absolute dualism" of two disconnected worlds, a realm of genuine being which never "appears" and a realm of sensible appearances which are merely unreal. What is true is that both *Phaedo* and *Republic* leave us with an unsolved problem. They tell us that a sensible thing is a complex or meeting-place of a plurality of Forms. What else, or what more, it is they do not tell us. And yet it is clear that a "thing" is not simply a bundle of "universal predicates."

Or, to put the point rather differently, according to the *Phaedo* a thing becomes for a while beautiful because Beauty "becomes present to it." But why does Beauty become present to this particular thing at just this particular moment? Clearly the relation between a "thing" and a Form which has been called "participation" needs further elucidation. Again the simple epistemological formula that knowledge is confined to Forms and their relations, while we can only have shifting "opinions" about temporal facts does less than justice to our scientific knowledge of the natural world; "truths of fact" have not yet come by their rights. Finally, if the Forms constitute a rationally ordered system, there must be definite principles of inter-relation between Forms themselves as well as between Forms and sensible things and these principles demand investigation. (If the Good is what the *Republic* says it is, not only will things "participate" in Forms; Forms also will "participate" in it.) Here are internal motives for active re-examination of the whole system.

It is clear that there was also an external motive. *Parmenides, Theaetetus, Sophistes,* all reveal a special interest in the Eleatic philosophy, and the first and third show an anxiety on Plato's part to maintain that, in spite of important divergences, he, and not the professed Eleatics, is the true spiritual heir of the great Parmenides. This is easily explained when we remember that Plato was personally a friend of the chief representative of Eleaticism among the Socratic circle, Eucleides of Megara, while Polyxenus of Megara, an associate of Eucleides, was a hostile critic of the doctrine of "participation."[1] The doctrine of Eucleides, like that of Parmenides was that "sensible appearances" are illusions with no reality at all. Against criticism from this quarter, it would be necessary for Plato to show that the *Phaedo* itself does not allow too much reality to the sensible; the attempt to prove this point would inevitably show that it had conceded too little. Continued reflection on the same problem of the worth of propositions about sensible fact leads straight to the discussion of the meaning of the *copula,* and the significance of denial, which is the subject of the *Sophistes.*

Parmenides.—Formally the dialogue conducts to an *impasse.* In its first half the youthful Socrates expounds the doctrine of the "participation" of things in Forms to the Eleatic philosophers, Parmenides and Zeno, as the solution of the problem of the One and the Many. Parmenides raises what appear to be insoluble objections to the conception of "participation," though he admits that "dialectic" would be impossible if the existence of Forms were denied; he hints that the helplessness of Socrates under his criticism arises from insufficient training in logic.

In the second and longer half, Parmenides gives an example of the logical training he recommends. He takes for examination his own thesis, "the One is," and constructs an elaborate set of antinomies after the fashion of Zeno, apparently proving that whether this thesis be affirmed or denied, in either case we are compelled either to affirm simultaneously or to deny simultaneously a series of contradictory predicates, alike of the "One" and of the "Many." The conclusion is patently ironical, and we are left to divine the author's purpose, if we can.

The objections to "participation," which is formulated precisely as in the *Phaedo,* are directed not against the existence of Forms, but against the possibility that sensible things should "participate" in them. From the point of view of this criticism Socrates' error is that he attributes some sort of secondary reality to the sensible. The main arguments are two: (1) the doctrine does not really reconcile unity with plurality, since it leads to a *regressus in indefinitum.* It says that the many things which have a common predicate "participate of" or "imitate" a single Form. But the Form itself also admits of the common predicate, and there must therefore be a second Form, "participated" or "imitated" alike by the sensible things and the first Form, and so on endlessly. We could not escape by the suggestion that the Form exists only "in our minds," since that would mean that a Form is a thought, and it would follow that "things" are made of thoughts. But if so, either everything thinks, or there are thoughts which do not think, and both alternatives are absurd; (2) it is a still graver difficulty that if there are two realms, a realm of Forms and a realm of sensible things, the relations between Forms must belong to the realm of Forms, those between sensible things to the realm of things. We ourselves belong to the second, and therefore all our knowledge belongs to it too; we know nothing of the true realities, the Forms: if anyone knows them, it is God, but God's knowledge, being knowledge of realities, will not extend to *our* world, the sensible. The purpose of the objections is thus to suggest that the "manifold of sense" has not even a derivative reality; it is mere illusion.

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[1] Alexander Aphrodis. on Aristot. *Met.* 990 b. 17.

This is precisely the position of the Eleatics and their Megarian continuators. The inference is that Plato is reproducing Megarian criticisms of the doctrine ascribed by himself to Socrates, an inference confirmed by the notice preserved by Alexander of Aphrodisias (on *Met.* 990 *b* 15) of the "third man" argument of the Megarian Polyxenus against "participation." Plato does not indicate his own opinion of the cogency of the reasoning, which is, in fact, fallacious, as was properly pointed out by Proclus.[1]

The purpose of the antinomies which follow has been very differently understood. In the present writer's opinion, they are deliberate parody, the object being to show that the methods of the Megarian logicians are even more damaging to their own fundamental metaphysical tenet than they are to the doctrine of "participation." Megarian logic is a double-edged weapon, and Plato, if he chooses, can apply it even more dexterously than its inventors.

Theaetetus.—Except for a magnificent interlude in praise of the contemplative life, the dialogue is a straightforward discussion of the question how knowledge should be defined. It naturally ends negatively. None of the proposed definitions will stand examination (the reason is that we are really trying to define truth and truth is an ultimate). But the incidental results of the discussion are of the first importance. We learn (*a*) that knowledge cannot be identified with sensation nor with any formless "simple apprehension"; (*b*) that pure relativism is as impossible in epistemology as in metaphysics. We have the beginning of a doctrine of the "categories" which is further developed in the *Sophistes*.

The increasing value which Plato is coming to put upon "natural knowledge" is marked by the use of the word δόξα, which in earlier dialogues had commonly meant mere uncertain "opinion" as contrasted with knowledge, in the new sense of "judgment" which it retains in Plato's subsequent work. The most striking negative feature of the *Theaetetus* is that it discusses knowledge at length without making any reference to the Forms and the mythology of "recollection." It remains to this day the best of introductions to the "problem of knowledge."

The main argument may be very briefly summarized thus: I. It seems plausible at first to say that knowledge (ἐπιστήμη) *is* sensation (αἴσθησις). This sounds very much like the proposition of Protagoras, "what seems to me is so to me; what seems to you is so to you." We might base such a thorough-going doctrine of the relativity of all knowledge on a still more ultimate metaphysical theory, if we said—it is implied that Protagoras himself said nothing of the kind—that, within us and without us, the only reality is motion. "Organ" and "environment" are both motions; when these motions impinge on one another, they give rise to the twin-product, felt sensation–sensible quality.

Both the sensation and the quality "sensed" will therefore be affected by any difference in the pair of slower "motions" which cause them (the "organ" and its "environment"), and each percipient, therefore, is confined to his strictly private world, which exists only "for" him. There is no "common" perceived world, and therefore no standard of truth or reality other than the individual percipient. A teacher does not aim, any more than a physician, at convincing his pupil of the "falsity" of his judgments, but at giving him "useful" or healthy convictions in place of harmful or diseased convictions.

The full discussion of such a theory would demand a thorough study both of the Heracleitean philosophy, which says that there is nothing but motion, and the Eleatic philosophy which says that motion is an illusion. But for our immediate purpose, a more summary argument is sufficient. It is certain that even the relativists, who hold that each man is the one infallible "measure" of his *present* perceptions, do not hold that he is the only and inerrant measure of his *future* sensations. A physician can often judge better than his patient whether the patient is going to have, *e.g.*, the sensations of an ague. A man's own opinion whether a certain course will be expedient or good for him is often far from being the soundest. We must distinguish carefully between what the mind perceives "through bodily organs"—the data of sense—and the things she apprehends "by herself" (αὐτὴ δι' αὐτῆς) without "organs." These latter include number, sameness, difference, likeness, unlikeness, being, good, bad, right, wrong, *i.e.*, the great universal "categories" of fact and value. These are apprehended not by sense, but by thinking, and as they are the formal element in all knowledge, knowledge must be found not in our sensations, but in "the judgment (συλλογισμός) of the mind upon" them.

II. Is knowledge, then, "true judgment"? The statement implies that we know what we mean by "false" judgment, error. But is this the case? Error must not be confused with mere false recognition, misinterpretation of present sensation, since there are purely intellectual errors, and we find ourselves unable to explain the nature of this kind of error. And, in fact, it is clear that persuasive rhetoric may produce in the hearer judgments which are true, but have no claim to be called knowledge. III. Finally, is knowledge "true judgment accompanied by discourse (μετὰ λόγου), true judgment for which we can give grounds"? This would distinguish knowledge from "simple apprehension," and would harmonize with the theory of those who hold that knowledge is always of complexes, never of their simple constituents. But this doctrine has difficulties of its own, and, in any case, if we say that knowledge is true judgment + "discourse," the "discourse" meant must be a statement of the logical *differentia* of the object of which I have knowledge. The proposed definition therefore amounts to saying that knowledge is true judgment about an object + *knowledge* of the *differentia* of that object, and so is circular.

LATER DIALOGUES

Sophistes and Politicus.—Formally these two important dialogues are closely connected. They are made to appear as a sequel to the *Theaetetus*, and a further connection is afforded between them by the fact that both are ostensibly concerned with a problem of definition, which is treated by the characteristic Platonic method of repeatedly subdividing a *genus* until we obtain the *definiendum* as a sub-species. The real purpose of the *Sophistes* is logical or metaphysical; it aims at explaining the true nature of negative predication and so disposing of the Eleatic thesis that the temporal and sensible realm, containing, as it does, a negative moment, must be mere unreal illusion. The object of the *Politicus* is to consider the respective merits of two contrasted forms of government, "personal rule" and "constitutionalism," and to recommend the second, particularly in the form of "limited monarchy," as most suitable to the actual condition of mankind. The *Sophistes* lays the foundations of all subsequent logic, the *Politicus* those of all "constitutionalism."

A more temporary purpose in both dialogues is to illustrate the value of careful classification as a basis for scientific definition. In both dialogues Socrates is almost silent; his place as chief speaker is taken by an unnamed and very unorthodox Eleatic, who seems to be a purely fictitious character. Plato is, in fact, claiming that he, and not the formal logicians of Megara, is the continuator of Parmenides, much as Aristotle in his polemic against Xenocrates claims to be the true successor of Plato.

In the *Sophistes* the main discussion is led up to through a definition of the "sophist" as an "illusionist," a person who, by abuse of logic, produces the illusion, or false appearance, that nature and human life are alike riddled by insoluble contradictions. (This shows that the persons aimed at under the name "sophist" are the

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[1] For a detailed discussion of it, *see* A. E. Taylor, *Parmenides, Zeno and Socrates* (Transactions of Aristotelian Society, N. S. xvi. 234 ff.)

Megarian controversialists who make an illegitimate use of the dialectic of Zeno and Socrates.) Now the "sophist" himself would retort that this definition is senseless, for there can be no such thing as a false statement or a false impression. For the false means "what is not," and "what is not" is nothing at all, and can neither be uttered nor thought. To refute him we need to correct the fundamental thesis of so venerable a thinker as Parmenides.

We must either admit that there can be no false statements, or we must be prepared to maintain that "what is not, in some sense also is," and "what is, in some sense is not" (*i.e.*, we must explain what is the meaning of a significant negative proposition). In our theory of "being" we have to meet at once Parmenides and two different types of pluralist opponents of Parmenides, (*a*) the corporealists who say that the real, "what is," is just visible and tangible body, and (*b*) certain "friends of Forms" who maintain that the real is a multitude of incorporeal Forms, denying that sense-perception gives us any apprehension of it. The corporealist is sufficiently refuted by the consideration that he himself cannot deny the reality of "force" (*δύναμις*) and that force is not a body. The incorporealist "friends of Forms" cannot be met in this way. They regard force, or activity itself as belonging to the unreal realm of "becoming." We meet them by urging that knowing is itself an activity and that we cannot deny intelligence and knowledge to the supreme reality. This means that it has a "soul" and is alive. But if life is real, movement and repose from movement must be real too.[1]

This leaves us free to attack the Parmenidean Monism itself. That is refuted by drawing the distinction between absolute and relative "non-being." A significant denial, *A is not B*, does not mean that *A* is nothing, but that *A* is other than *B*. Every one of the great categorical features of reality is other than every other, and the true business of "dialectic" is to study the various possible combinations of these universal "categories." The dialogue mentions five of them, being, identity, difference, motion and rest. It is not said that this is a complete list of "categories," though it was treated as such by the Neo-Platonists.

The important result is thus that we have learned to think of Forms themselves as an inter-related system, with relations of compatibility and incompatibility among themselves. Negation is a moment in the system of intelligible reality, and therefore its presence in the sensible realm does not stamp that realm as illusion. This is the ontological position which interests Plato; the recognition of the function of the logical *copula* is a consequence.

The *Politicus* has as its main result the conclusion that government by the personal direction of a benevolent "dictator" is not suitable to the conditions of human life, where the direction is necessarily that of a fallible man, not of a god. In an actual human society, the surrogate for personal direction by a god is the impersonal supremacy of inviolable law. Where there is such a recognized sovereign law, monarchy is the most satisfactory type of constitution, democracy the least satisfactory, but where there is no "fundamental law," this situation is inverted. A "sovereign" democracy is preferable to an irresponsible autocrat. The dialogue is rich in thoughts which have passed into the substance of Aristotle's ethics and politics. Aristotle took directly from it the conception of "politics" as the "architectonic" practical science to which all others are subordinate; the formula of the "right mean" comes from it together with the *Philebus*.

Philebus.—The subject of the dialogue is a strictly ethical one, and this, no doubt, explains why it is the only dialogue after the *Theaetetus* in which Socrates is the principal speaker. The issue propounded is the question whether the "good" is pleasurable feeling or whether it is thought, the exercise of intelligence.

Comparison with the notices of Aristotle in the *Nicomachean Ethics* shows that this was the subject of a sharp division in the Academy, the Hedonist party being led by the mathematician and astronomer Eudoxus, the anti-Hedonists by Speusippus. Under the guidance of Socrates the question is narrowed down to a consideration of the good for *man* in particular, and a mediating conclusion is reached. The best life for man contains both elements, but intelligence is the "predominant partner."

All forms of knowledge find a place in it, but only those pleasures which are compatible with wisdom and virtue, *i.e.*, those which are "unmixed," not preceded by a sense of want or craving, and those of the "mixed" pleasures, the satisfactions of appetite, which are innocent and moderate. The *Philebus* contains Plato's ripest moral psychology; it is the immediate source of the famous "doctrine of the Mean."

Philosophically the most important feature of the dialogue is a classification adopted with a view to determining the formal character of the two claimants to recognition as the good. All components of the actual belong to one of four classes, (1) the infinite or unbounded (*ἄπειρον*), (2) the limit (*πέρας*), (3) the mixture or combination of (1) and (2), (4) the cause of the mixture. ([1] and [2] are just the two fundamental "opposites" of Pythagoreanism.) All the good things of life belong to (3), that is, they are produced by the introduction of definite "limit" or "ratio" into an indeterminate "continuum." (This is precisely the doctrine of the "Mean.") The establishment of such a "ratio" is a *γένεσις εἰς οὐσίαν*, a process resulting in a stable "being," and it is indicated that the cause or agent in such a process is always intelligence, human or divine.

There has been much discussion of the question in which of these "classes" the Forms should be placed. The only tenable alternatives would be to put them into the class of "limit" or into that of the "mixture" (a view suggested both by the teaching of the *Sophistes* and by Aristotle's express statement that Plato distinguished two constituents within the Form and advocated ably by Dr. H. Jackson). The truth seems to be that the particular classification in the *Philebus* is devised for a special purpose, and that it is not intended to apply to anything but the things and processes of the sensible realm. In that case, though there is a close correspondence between what the *Philebus* teaches about "stable being" in the sensible realm and what, as we know from Aristotle, Plato taught about the Forms, it will be a mistake to look for any actual exposition of the metaphysic of the Forms in the *Philebus*.

Timaeus.—The *Timaeus* is an exposition of cosmology, physics and biology put into the mouth of the astronomer Timaeus of Locri. Though Plato avoids expressly describing the speaker as a Pythagorean, his doctrine is revealed by attentive analysis as an attempt to combine the mathematics and astronomy of the Pythagoreans with the biology of Empedocles, the real founder of Sicilian medicine. The discussion is introduced by the famous narrative of the gallantry of the prehistoric Athenians who defeated the kings of the imaginary Atlantis in their ambitious attempt to become masters of the world. The story was to have been told more in detail in the unfinished *Critias*.

Timaeus opens his discussion by drawing a sharp distinction between eternal being and temporal becoming, and insisting on the point that it is only of the former that we can have exact and final knowledge. All accounts of the temporal can be only tentative and liable to repeated revision. Cosmology, then, at best, is not exact science. The visible world, being mutable and temporal, is a copy of a model which is eternal, and the copy is the work of God. The reason why there is a copy at all is the unceasingly active and generous goodness of God. (In the sequel Timaeus speaks of the Forms which God had before Him as His model in much the same language as the *Phaedo*, except that he uses the Pythagorean word "imitation," not "participation," to describe the relation of sensible things to Forms.)

The world, then, had a beginning. (The Academic tradition from the first was that this is not to be understood literally; Aristotle insists on taking it literally.) God first formed its soul out of three constituents, Identity, Difference, Being. Its body was made later from the four Empedoclean "elements." The world-soul was placed in the circles of the sidereal Equator and Ecliptic, the latter being split into seven lesser circles, those of the planets, and the two were animated with movements in opposite senses. Subsequently were formed the various subordinate gods and the souls of human beings, that is the "immortal" and rational element in the human soul, which come straight from the hands of God Himself. The formation of the human body and of the two lower "mortal" components of the human soul was effected through the intermediacy of the "created gods" (*i.e.*, the stars). The most important question of detail arising from this part of the dialogue is that debated between Boeckh and Grote. Does Timaeus ascribe a motion to the earth? The restoration of the correct text at 40*c*[1], proves definitely that he does, but it is not a diurnal revolution, as Grote supposed; it must be rectilinear displacement of unknown period. The contact is made between Pythagorean geometry and the Empedoclean biology which will be needed for the physiology and medicine of the dialogue by a mathematical construction of the "elements."

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[1] It is still a much agitated question who are the "logical atomists" described in the *Sophistes* as the "friends of Forms." The view that they are adherents of the philosophy of the *Phaedo* and *Republic* is deservedly dead. They are still often supposed to be Megarians, but this seems inconsistent with the way in which they are carefully distinguished from the followers of Parmenides as belonging to "the other side" at 245 *e*. Proclus (*in Parm.* 562 St.) says positively, as though it were the only view known to him, that they are Italian Pythagoreans, and this is probably correct, since the Eleatic of the dialogue refers to them as persons with whom he is "familiar." It is important to remark that the identification of "being" with "force" is given merely as a consequence which would follow from, and contradict, the corporealist "hypothesis." The implication of the passage is rather that the identification is false than that it is true.

Starting with two primitive triangles, the isosceles right-angled, and the right-angled scalene in which the hypotenuse is double the shortest side, Timaeus constructs four of the regular solids, cube, tetrahedron, octahedron, icosahedron, and these are assumed to be the shapes of the corpuscles of earth, fire, air, water. These four in their turn are the immediate constituents of all organic and inorganic compounds.

The important features of the dialogue are not the particular tentative scientific hypotheses but its leading methodological principles. We should note the introduction of God as the intelligent efficient cause of all order and structure in the world of "becoming," which preludes to the natural theology of the *Laws*, and the emphatic recognition of the essentially tentative, and therefore progressive, character of natural science. It is also noticeable that though Plato's scientific ideal is a mathematical corpuscular physics—his influence in creating this ideal has been much more important than that of the ancient Atomists—he constructs his physical world without "matter" as a metaphysical "substrate." The place of matter is taken in his analysis, as Aristotle complained, by *χώρα*, space, as in the *Principia* of Descartes, a point of view to which physical speculation seems to be returning. He analyses the "passage of Nature" into three factors: *ὄν* ("being": a Form), *χώρα* (space), *γένεσις* (happening), much as Whitehead analyses it into "objects," "events" and the "ingredience of object into event."

It is a fundamental point that the presence of *χώρα* as a factor makes it necessary to recognise over and above "God" or "mind" a subordinate element of *ἀνάγκη*, "necessity" in events. Since necessity is also called the "errant" cause, *πλανωμένη αἰτία* (with an allusion to the name of the "planets" or "tramp-stars") the word clearly does not mean "conformity to law." It is rather a name for the fact that there is always in the actual an irreducible remainder of "brute" datum, "conjunctions" in Hume's phrase, which we cannot rationalize completely into intelligible "connections." Thus *ἀνάγκη* is not a rebel or evil principle in the constitution of things; its function is everywhere to be instrumental to the intelligent and beneficent purpose of "mind" or God. There are many facts which we have to be content to accept simply as facts without seeing their "reason why." We do not know and may never know, why it is "best" that they should be as they are—*e.g.*, why "it is best" that we should live on a moving earth—but we may be sure that, since it is the fact, it is in some way best that it should be so. This seems to be what is meant by the statement that God or "mind" (*νοῦς*) persuades *ἀνάγκη*. It is the expression of a rational faith in Providence and the supremacy of the moral order. The details of the cosmology, physiology and psycho-physics of the dialogue are of great importance for the history of science, but metaphysically of secondary interest.

Laws and Epinomis.—The *Laws*, Plato's longest, is also his most intensely practical work, and contains his ripest utterances on ethics, education and jurisprudence, as well as his one entirely non-mythical exposition of theology. The immediate object is to meet a practical need by providing a model of constitution-making and legislation for members of the Academy who may be called on to assist as advisers in the actual founding or re-founding of cities.

Plato's attempt to do work of this kind himself, at Syracuse, had borne no immediate fruit, but had given the Academy a recognized standing as a school of scientific politics and jurisprudence. The work of constitution-making and legislation was going on in many quarters at the end of his life, and his experience might be made fruitful in sage counsels to younger men. The practical character of the subject explains some novelties in the outward form of the work. As the dialogue is assumed to be dealing with the actual present, Socrates has disappeared and his place is taken by an unnamed Athenian who is, to all intents, Plato himself.

The scene is laid in Crete; the imagined situation is that the Cretans are about to found a settlement on the site of a long deserted city. The chief Commissioner for the project is walking out to inspect the proposed site with a Spartan friend, when they fall in with the Athenian, and being favourably impressed by his conversation invite him to join them as an "expert adviser."

The problem thus differs from that of the *Republic;* the question is not the construction of an ideal Utopia, but the framing of a constitution and code which might be successfully adopted by a society of average Greeks in the middle of the fourth century. Hence the demands made on average human nature, though exacting, are not pitched too high; the communion of the *Republic* is dropped. And for the same reason it is assumed all through that the regulations are carefully adapted to the particular economic and geographical conditions, though it is said that these conditions will not really suit any actual Cretan locality. If so, we must suppose that Plato, under a transparent disguise, is contemplating the actual conditions in quarters from which the Academy was more likely to receive appeals for help.

The special purpose of the work also explains why purely speculative philosophy and science are excluded from its purview. The metaphysical interest is introduced only so far as to provide a basis for a moral theology; the one matter of first-rate scientific importance touched on is the diurnal motion of the earth, and this is only hinted in connection with the practical problem of the construction of the Calendar. In compensation, the *Laws* is exceptionally rich in political and juristic wisdom, and appears, indirectly, through its influence on the law of the Hellenistic age, to have left its mark on the great system of Roman jurisprudence.

It is impossible to do more than to call attention to a few of the striking features of this great work. The ethical ideal is still that familiar from earlier dialogues. It is interesting that the demand is expressly made that all "unnatural" vices shall be completely suppressed, and that the rule of sexual life is to be monogamous marriage with strict chastity, outside the limits of marriage, for both sexes. In politics, Plato declares himself definitely in favour of a "mixed" constitution; a good government demands a balance between two principles, *ἐλευθερία*, "popular control," and *μοναρχία*, "personal authority." Persia is an illustration of the mischief of unqualified autocracy, Athens of the evils which come from elimination of the "authoritarian" principle, and considerable care is taken in the suggested system of magistracies to secure both genuine "popular representation" and the proper regard for personal qualifications. The basis of society is to be agriculture, not commerce; the citizens are to be "peasant proprietors"—communism is regretfully abandoned as impracticable in a society of ordinary human beings. But the patrimony of each household is to be strictly inalienable, and differences in "personal" property are to be kept within strict bounds by what amounts to a super-tax of 100% on incomes beyond the statutory limits. Education, as in the *Republic,* is regarded as the most important of all the functions of government; it is placed under the control of a minister who is the "premier." As far as possible, the distinction between the sexes is, as in the *Republic,* to be treated as irrelevant to the educational programme.

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[1] The words used of the earth *ἰλλομένην τὴν περὶ τὸν διὰ παντὸς πόλον τεταμένον* admit of only one rendering "going up and down on the path about the axis of the universe." Timaeus thinks of the earth as placed about the axis of the whole universe and being displaced to North and South by a sliding movement along this axis. Aristotle was then exactly right in saying that Timaeus teaches that the earth "is at the centre" and moves there (*de Coelo* 293 *b*30) and distinguishing this view carefully from that which he ascribes to the Pythagoreans, "that the earth revolves as a planet about the centre." It is this second view which is implied in the language of *Laws* 822*a* and *Epinomis* 987*b* and expressly attributed to Plato "in his later years" by Theophrastus ap. Plutarch *Quaest. Plat.* 1006*c*. There is no reason to suppose that Plato ever himself held the curious view he has ascribed to his fifth century Pythagorean. He has his own reasons for insisting as strongly as he does on the provisional character of all the science of the dialogue.

The most striking features of the scheme are the careful attention paid to the problems of the physical training of children in their earliest infancy, and the right utilization of the child's instinct for play, and the demand, made now for the first time, that in adolescence, the young shall be taught in institutions where expert instruction in all the various subjects is co-ordinated. It is from this proposal that the "grammar school," or secondary school, has taken its origin. Though we hear no more of "philosopher-kings" the demand is still made that the members of the "Nocturnal Council," the supreme Council of the State, which is always in permanent session, and exercises a general control over administration, shall be thoroughly trained, not only in the exact sciences, but in the supreme science, which "sees the One in the Many and the Many in the One;" that is, they are to be "dialecticians."

The work is full of suggestions for the practical application of science, such, for example, as that of the necessity of strictly standardizing all weights and measures, or that of basing the Calendar on a solar year (of 365 days). The object of the apparently arbitrary selection of the number of patrimonies and the scheme of sub-division of the whole society into smaller groups appears to be the practical one of making it easy to determine exactly what quotum each subdivision may justly be called on to contribute to the revenue or the defences.

At least two fundamental improvements are made on the Attic jurisprudence which Plato has adopted as the foundation of his own code. One great blot on the Heliastic system is removed by the regulations which ensure that trials for serious offences shall take place before a court which contains highly qualified magistrates, and shall proceed with due deliberation, and that there shall be provision for appeals from the primary tribunal to a "Court of Cassation." It is even more important, perhaps, that *Laws* IX. by drawing a clear distinction between *βλάβη,* detriment, and *ἀδικία,* infringement of rights, lays the foundation for the discrimination between civil and criminal actions at law.

An incidental passage in the Laws (822 *a-b*) and another in the *Epinomis* (987*b*) definitely show that Theophrastus was right in crediting Plato with belief in the earth's motion. In the *Laws* it is said that the real orbit of each planet is a single closed curve, in the *Epinomis* the view that the "circle of the stars" communicates its motion to those of the planets is called that of men "who know but little of the subject." The allusion is to he famous theory of the celestial motions put forward by Plato's friend and associate, the great mathematician Eudoxus.

According to this, the first great "geocentric" theory in scientific astronomy, the movements of each planet can be analyzed nto a combination of circular revolutions, the unmoved earth being taken as the common centre of all. What Plato asserts is hat each planet has only one "proper" revolution, the remaining revolutions are apparent, not real. The implication is that these apparent revolutions of the planet must be real motions of the earth from which we make our observations. The earth is thus a planet, though not a satellite of the sun. The language of the *Epinomis*—which may be safely regarded as at least true to Plato's thought—definitely makes the sun, itself, one of the planets. We have, therefore, to think of the earth as also a planet revolving with the rest round an unseen centre. We may nfer from the words of Theophrastus that Plato, like some of the Pythagoreans, held that there is a luminary, the "central fire," at this centre. The period of the earth's revolution would certainly be taken to be the natural day, so that the motion ascribed to the earth is equivalent to the diurnal rotation, though from Plato's point of view, it is not a rotation on an axis, but a revolution round a centre. It follows that the alternation of day and night is no longer accounted for by a rotation of the "heaven of the fixed stars." This "outermost circle" is still credited in the *Epinomis* with a revolution in the sense E. to W., but its period is not specified. We need not suppose either that Plato could have specified the period or that he used it to explain any special appearances.[1]

What is to Plato's credit is that he has the insight to see that, with all its attractions, the scheme of Eudoxus starts from a wrong pre-supposition, a stationary earth.

In *Laws X.* Plato, for a practical purpose, creates natural theology. There are three false beliefs which are fatal to moral character, atheism, denial of the moral government of the world, the belief that divine judgment can be bought off by offerings. Plato holds that he can disprove them all. The refutation of atheism turns on the identification of the soul with the "movement which can move itself," already used in the *Phaedrus.* All motion is either communicated from without or self-initiated, and the ultimate source of all communicated motion must be self-initiated motion. The only thing which can move itself is a soul. It follows that all motion throughout the universe is ultimately initiated by souls. It is then inferred from the regular character of the great cosmic motions and their systematic unity, that the souls which originate them form a hierarchy with a "best soul," God, at their head. Disorderly and irregular motions are equally due to souls, but to bad and disordered souls, and since there are disorderly motions, it is inferred that the "best soul" cannot be the only soul.

There is no suggestion that there is a "worst soul," a "devil" or "evil world-soul"; all that is said is that there *must* be one soul which is not the best, and may be more. This is Plato's way of excluding Pantheism, as incompatible with the reality of evil. The argument thus establishes at once the immortality of the soul and the existence of God. The other two heresies can now be disposed of. It is inconsistent with the goodness of the best soul to be indifferent to our conduct, and still more so to be venal. The moral government of the world is, in fact, assured by the establishment of the single principle that every soul gravitates into the society of its likes, and consequently "does and has done to it what it befits such a soul to do and have done to it." Plato thus becomes definitely the originator of the view, that there are certain theological truths which can be strictly demonstrated by reason.

It is these demonstrable truths which are subsequently named by Varro "natural" or "philosophical" theology in contradistinction to the "poetical theology," the myths related by the poets, and the "civil theology," the ritual cultus instituted by politicians. From Varro the distinction of three theologies passed to St. Augustine, and thus in the end became the foundation of the scholastic distinction between natural theology, those truths about God which can be ascertained independently of any specific revelation, and revealed theology, the further truths which are only made accessible by the Christian revelation. Since Plato's object in demonstrating his three propositions is an ethical one, he goes on to enact that the maintenance of any of them shall be a grave crime to be visited by the State with penalties ranging from a minimum of five years' solitary confinement, and with death on a second conviction. Plato is thus the inventor, so far as European society is concerned, of the proposal to make an official creed for the State and to treat dissent from it as criminal, an innovation foreign to the spirit of the Hellenic cities, in which religion was a matter not of beliefs but of cultures. Plato's last word, then, on the problem how the sensible comes to "partake" of Form is that it does so through the agency of divine goodness and wisdom. God moulds the sensible upon the pattern of the intelligible. The obvious question, how God, who is a "soul" not a Form, is related to "the Good" which is the supreme Form never receives discussion or solution. To answer it was to be the main business of Plotinus.

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[1] It has nothing to do with "precession of the equinoxes," being in the wrong sense for that purpose.

PLATONISM AFTER PLATO

Aristotle's Account of Platonism.—Since Plato refused to write any formal exposition of his own metaphysic, our knowledge of its final shape has to be derived from the statements of Aristotle, which are confirmed by scanty remains of the earliest Platonists preserved in the Neo-Platonist commentaries on Aristotle. These statements can, unfortunately, only be interpreted conjecturally. According to Aristotle (*Metaphysics, A* 987, *b* 18–25) Plato's doctrine of Forms was, in its general character, not very different from Pythagoreanism, the Forms being actually called Numbers. The two points on which Aristotle regards Plato as disagreeing with the Pythagoreans are, that (1) whereas the Pythagoreans said that numbers have as their constituents, the unlimited (*ἄπειρον*) and the limit (*πέρας*), Plato taught that the forms have as constituents "the One" and the "great and small"; (2) the Pythagoreans had said that things are numbers, but Plato intercalated between his Forms (or Numbers) and sensible things an intermediate class of "mathematicals." It is curious, that in connection with the former difference Aristotle dwells mainly on the substitution of the "duality of the great-and-small" for the "unlimited," not on the much more significant point that the "One," which the Pythagoreans regarded as the simplest complex of unlimited and limit, is treated by Plato as itself the element of limit. He further adds that the "great-and-small" is, in his own technical terminology, the "matter," the One, the formal constituent, in a Number.

If we could be sure how much of the polemic against Number-Forms in *Metaphysics M-N* is aimed directly at Plato, we might add considerably to this bald statement of his doctrine, but unluckily it is certain that much of the polemic is concerned with the teaching of Speusippus and Xenocrates. It is not safe, therefore, to ascribe to Plato statements other than those with which Aristotle explicitly credits him. We have then to interpret, if we can, two main statements: (1) the statement that the Forms are Numbers; (2) the statement that the constituents of a Number are the "great-and-small" and "the One."

Light is thrown on the first statement if we recall the corpuscular physics of the *Timaeus* and the "mixture" of the *Philebus*. In the *Timaeus*, in particular, the behaviour of bodies is explained by the geometrical structure of their corpuscles, and the corpuscles themselves, are analysed into complexes built up out of two types of elementary triangle, which are the simplest "elements" of the narrative of Timaeus. Now a triangle, being determined in everything but "absolute magnitude" by the numbers which express the ratio of its sides, may be regarded as a triplet of numbers.[1] If we remember then, that the triangles determine the character of bodies, and are, themselves, determined by numbers, we may see why the ultimate Forms on which the character of Nature depends should be said to be Numbers, and also what is meant by the "mathematicals" intermediate between the Forms and sensible things. According to Aristotle, these "mathematicals" differ from Forms because they are many, whereas the Form is one, from sensible things in being unchanging. This is exactly how the geometer's figure differs at once from the type it embodies and from a visible thing. There is, for example, only one type of triangle whose sides have the ratios 3:4:5, but there may be as many "pure" instances of the type as there are triplets of numbers exhibiting these ratios; and again, the geometrical triangles which are such "pure" instances of the type, unlike sensible three-sided figures, embody the type exactly and unchangingly. A mathematical physicist may thus readily be led to what seems to be Plato's view that the relations of numbers are the key to the whole mystery of nature, as is actually said in the *Epinomis* (990*e*).

We can now, perhaps, see the motive for the further departure from Pythagoreanism. It is clear that the Pythagorean parallelism between geometry and arithmetic rested upon the thought tha the "point" is to spatial magnitude what the number 1 is to number. Numbers were thought of as collections of units, and volumes, as, in like fashion, collections of points; that is, the poin was conceived as a minimum volume. As the criticisms of Zeno showed, this conception was fatal to the specially Pythagorean science of geometry itself, since it makes it impossible to asser the continuity of spatial magnitude. (This, no doubt, is why Plato, as Aristotle tells us, rejected the notion of a point as a fiction.)

There is also a difficulty about the notion of a number as a "collection of units," which must have been forced on Plato's attention by the interest in "irrationals" which is shown by repeated allusions in the dialogues, as well as by the later anecdotes which represent him as busied with the problem of "doubling the cube" or finding "two mean proportionals." "Irrational" square and cube roots cannot possibly be reached by any process of forming "collections of units," and yet it is a problem in mathematics to determine them, and their determination is required for physics (*Epin.* 990*c*–991*b*).

This is sufficient to explain why it is necessary to regard the numbers which are the physicist's determinants as themselves determinations of a continuum (a "great and small"), by a "limit" and why, at the same time "the One" can no longer be regarded as a "blend" of "unlimited" and "limit" but must be, itself, the factor of "limit." (If it were "the first result" of the blending it would re-appear in all the further "blends"; all numbers would be "collections of one" and there would be no place for the "irrationals.") There is no doubt that Plato's thought proceeded on these general lines. Aristotle tells us that he said that numbers are not really "addible"(*οὐ συμβλητοὺς εἶναι τοὺς ἀριθμοὺς πρὸς ἀλλήλους, Met* M 1083 *a* 34), that is that the integer-series is not really made by successive additions of 1[2], and the *Epinomis* (*wc. cit.*) is emphatic on the point that contrary to the accepted opinion, "surds" are just as much numbers as integers. The underlying thought is that numbers are to be thought of as generated in a way which will permit the inclusion of rationals and irrationals in the same series. In point of fact there are logical difficulties which make it impossible to solve the problem precisely on these lines. It is true that mathematics requires a sound logical theory of irrational numbers, and again, that an integer is not a "collection of units"; it is not true that rational integers and "real numbers" form a single series.

The Platonic number-theory was inspired by thoughts which have since borne fruit abundantly, but it was itself premature. We learn partly from Aristotle, partly from notices preserved by his commentators, that in the derivation of the integer-series, even numbers were supposed to be generated by the "dyad" which "doubles" whatever it "lays hold of," odd numbers in some way by "the One" which "limits" (*ὁρίζει*) or "equalises" (*ἰσάζει*), but the interpretation of these statements is, at best, conjectural. In the statement about the "dyad" there seems to be some confusion between the number 2 and the "indeterminate dyad," another name for the continuum also called the "great-and-small," and it is not clear whether this confusion was inherent in the theory itself, or has been caused by Aristotle's misapprehension.

Nor, again, is it at all certain exactly what is meant by the operation of "equalising" ascribed to the One.[3] It would be improper here to propound conjectures which our space will not allow us to discuss.

The Academy After Plato.—Though Plato's Academy produced only one later philosopher of the first order, it continued to exist as a corporate body down to the year 529 A.D. when the Emperor Justinian, in his zeal for Christian orthodoxy, closed the schools of Athens and appropriated their emoluments. Plato's greatest scholar, Aristotle, finally went his own way and organised a school of his own in the Lyceum, claiming that he was preserving the essential spirit of Platonism, while rejecting the difficult doctrine of the Forms; the place of official head of the society was filled first by Speusippus, Plato's nephew (347–339 B.C.), then by Xenocrates (339–314 B.C.). Under Arcesilaus (276–241 B.C.) the Academy began its long-continued polemic against the sensationalist dogmatism of the Stoics, which accounts both for the tradition of later antiquity which dates the rise of a "New" (some said "Middle") and purely sceptical "Academy" from Arcesilaus, and for the eighteenth-century associations of the phrase "academic philosophy."

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[1] Thus the two fundamental triangles of Timaeus may be called the triplets $(1,1,\sqrt{2})$ $(1,\sqrt{3},2)$ respectively.

[2] 2, for example, does not "contain" two 1's, 2 is not "1 and another 1"; it is "the integer after 1."

[3] A full collection and examination of all the available evidence is given by L. Robin in his *Théorie platonicienne des Idées et des Nombres d'après Aristote* (1908), and an admirable exposition of the significance of the problem of the irrational for Plato's philosophy by G. Milhaud in *Les philosophes-géomètres de la Grèce, Platon et ses prédécesseurs* (1900). For a recent conjectural interpretation *see* A. E. Taylor's essay, "Forms and Numbers," in Mind, N.S. 140, 141.

In the first century B.C. the most interesting episode in the history of the school is the quarrel between its President, Philo of Larissa and his scholar Antiochus of Ascalon, of which Cicero's *Academica* is the literary record. Antiochus, who had embraced Stoic tenets, alleged that Plato had really held views indistinguishable from those of Zeno of Cittium, and that Arcesilaus had corrupted the doctrine of the Academy in a sceptical sense. Philo denied this. The gradual *rapprochement* between Stoicism and the Academy is illustrated from the other side by the work of Stoic scholars like Panaetius of Rhodes, and Poseidonius of Apamea, who commented on Platonic dialogues and modified the doctrines of their school in a Platonic sense.

The history of the Academy after Philo is very obscure, but early in our era we meet with a popular literary Platonism of which the writings of Plutarch are the best example. This popular Platonism insists on the value of religion, in opposition to Epicureanism, and on the freedom of the will and the reality of human initiative, in opposition to the Stoic determinism; a further characteristic feature, wholly incompatible with the genuine doctrine of Plato, is the notion that matter is inherently evil and the source of moral evil.

Genuine Platonism was revived in the third century A.D. at Rome, and independently of the Academy, by Plotinus. His Neo-Platonism (*q.v.*) represents a real effort to do justice to the whole thought of Plato, but there are two sides of it which inevitably, in the changed conditions, fell into the background, the mathematical physics and the politics. The third century A.D. had no understanding for the first, and the Roman Empire under a succession of military chiefs no place for the second. The doctrine of Plotinus is Platonism seen through the personal temperament of a saintly mystic, and with the *Symposium* and the teaching of the *Republic* about the "Form of Good" always in the foreground. Plotinus lived in an atmosphere too pure for sectarian polemic, but in the hands of his successors, Neo-Platonism was developed in conscious opposition to Christianity. Porphyry, his disciple and biographer, was the most formidable of the anti-Christian controversialists; in the next century, "Platonists" were among the allies and counsellors of the Emperor Julian in his ill-advised attempts to invent an Hellenic counterpart to Christianity.

Early in the fifth century, Neo-Platonism flourished for a short time in Alexandria (which disgraced itself by the murder of Hypatia in 415) and captured the Athenian Academy itself, where its last great representative was the acute Proclus (A.D. 410–485). The latest members of the School, under Justinian, occupied themselves chiefly with learned commentaries on Aristotle, of which, those of Simplicius are the most valuable. The doctrine of the school itself ends in Damascius with complete agnosticism.

Influence on Christian Thought.—Traces of Plato are probably to be detected in the Alexandrian *Wisdom of Solomon;* the thought of the Alexandrian Jewish philosopher and theologian Philo, at the beginning of our era, is at least as much Platonic as Stoic. There are, perhaps, no certain marks of Platonic influence in the New Testament[1], but the earliest apologists (Justin, Athenagoras) appealed to the witness of Plato against the puerilities and indecencies of mythology. In the third century Clement of Alexandria, and after him, Origen, made Platonism the metaphysical foundation of what was intended to be a definitely Christian philosophy. The Church could not, in the end, conciliate Platonist eschatology with the dogmas of the resurrection of the flesh and the final judgment, but in a less extreme form the Platonizing tendency was continued in the next century by the Cappadocians, notably St. Gregory Nyssen, and passed from them to St. Ambrose of Milan. The main source of the Platonism which dominated the philosophy of western Christian divines through the earlier Middle Ages, were, however, Augustine, the greatest thinker among the Western Fathers, who had been profoundly influenced by Plotinus, read in a Latin version, before his conversion to Christianity, and Boethius, whose wholly Platonist vindication of the ways of Providence in his *Consolatio Philosophiae* was the favourite "serious" book of the Middle Ages.

A further powerful influence was exerted by the writings of the so-called Dionysius the Areopagite, which laid down the main lines of mediaeval mystical theology and angelology. These works are, in fact, an imperfectly Christianized version of the speculations of Proclus, and cannot date before the very end of the fifth century A.D. at the earliest, but they enjoyed an immense authority based on their attribution to an immediate convert of St. Paul.

After their translation into Latin in the ninth century by Johannes Scotus Erigena, their vogue in the West was as great as in the East. Apart from this theological influence, Plato dominated the thought of the earlier Renaissance which dates from the time of Charlemagne in another way. Since the West possessed the philosophical writings of Cicero, with the Neo-Platonic comment of Macrobius on the *Somnium Scipionis*, as well as the Latin translation of the first two-thirds of the *Timaeus* by Chalcidius, with his commentary on the text, and versions, also, at least of the *Phaedo* and *Meno*, whereas nothing was known of the works of Aristotle except Latin versions of some of the logical treatises, the Middle Age, between Charlemagne and the beginning of the 13th century, when the recovery of Aristotle's physics and metaphysics from Moors, Persians and Jews began, was much better informed about Plato than about Aristotle; in particular in the various "encyclopaedias" of this period, it is the *Timaeus* which forms the regular background.

The thirteenth century saw a change. Aristotle came to displace Plato as "the philosopher," partly in consequence of the immediately perceived value of his strictly scientific works as a storehouse of well-digested natural facts, partly from the brilliant success of the enterprise carried through by St. Thomas Aquinas, the reconstruction of philosophical theology on an Aristotelian basis. Plato is, however, by no means supplanted in the Thomist system; the impress of Augustine on Western thought has been far too deep for that. Augustine's "exemplarism," that is, the doctrine of Forms in the version, ultimately derived from Philo of Alexandria, which makes the Forms "creative thoughts" of God, is an integral part of the Thomist metaphysics, though it is now denied that the exemplars are themselves cognizable by the human intellect, which has to collect *its* "forms," as best it can, from the data of sense.

Directly or through Augustine, the influence of Plato, not only on strictly philosophic thought but on popular ethics and religion, has repeatedly come to the front in ages of general spiritual requickening, and shows no signs of being on the wane.

Two "revivals" in particular are famous. The first is that of the 16th century, marked by the Latin translation of Marsilio Ficino and the foundation of Lorenzo dei Medici's fantastic Florentine Academy. What was revived then was not so much the spirit of Plato as that of the least sober of the Neo-Platonists; the influence of the revival was felt more in literature than in philosophy or morals, but in literature its importance may be measured by the mere mention of such names as Michelangelo, Sidney, Spenser.

In the 17th century, Plato, seen chiefly through the medium of Plotinus, supplied the inspiration of a group of noble thinkers who were vindicating a more inward morality and religion against the unspiritual secularism and erastianism of Hobbes, the so-called "Cambridge Platonists," Whichcote, Henry More, Cudworth, John Smith. At the present moment the writings of A. N. Whitehead contain an attempt to work out a philosophy of the sciences which confessedly connects itself with the ideas of the Timaeus.

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[1] We may perhaps detect it in John i. 18 if the true text is "the only begotten God (μονογενὴς θεός) which is in the bosom of the Father." This may be an echo of the phrase used in the *Timaeus* (92*d*) about the visible world "A God apprehensible to sense . . . one and only begotten" (μονογενὴς ὤν). But it is not safe to assert it.

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PLATO, Athenian comic poet of the Old Comedy, flourished between 428–389 B.C. According to Suïdas, he was the author of 30 comedies. Some of these deal with political matters. Such were the *Cleophon* and *Hyperbolus,* directed against the well-known demagogues. His later plays are satires handled in a burlesque spirit. Such were the *Sophistae,* akin to the *Clouds* of Aristophanes; the *Cinesias,* an attack on a contemporary poet and the *Festivals.*

See T. Kock, *Comicorum atticorum fragmenta,* i. (1880); A. Meineke, *Poetarum comicorum graecorum fragmenta* (1855).

PLATON, LEVSHIN (1737–1812), Russian divine, was born at Chashnikovo near Moscow, and educated in the academy of that city. In 1763 the empress Catherine II. invited him to instruct her son Paul in theology, and he became one of the court chaplains. Three years afterwards Platon was appointed archimandrite of the monastery of the Trinity (Troitskaya Lavra) near Moscow, in 1770 archbishop of Tver, and in 1787 archbishop of Moscow and metropolitan. He died in 1812, one of his last acts having been to write an encouraging letter to the emperor Alexander I. in view of the French invasion. Platon was a brilliant and learned man, and the author of *A Short History of the Russian Church.*

PLATONIC LOVE, a term commonly applied to an affectionate relation between a man and a woman into which the sexual element does not enter. The term in English goes back as far as Sir William Davenant's *Platonic Lovers* (1636). It is derived from the conception, in Plato's *Symposium,* of the love of the idea of good which lies at the root of all virtue and truth.

PLATOON, a sub-division of a company of infantry. In the 17th century it was, in some cases, the infantry tactical unit and was commanded by a captain. At the beginning of the 18th century the term referred to a small body of musketeers of about 40 or 50 men arranged in a square to strengthen the angle of the battalion when formed in hollow square. About the middle of the 18th century a battalion was generally organized into 16 platoons, of about 24 men each, plus two or four platoons of grenadiers. In the 19th century, the term has been applied solely to a squad of recruits under training. "Platoon fire" was the systematic and regulated fire of platoon volleys. Hence a "platoon" sometimes meant a volley. The term was retained for a type of manual exercise. As a sub-division of an infantry company it was re-introduced into the British service in 1913 and is now the name of the sub-division of a company in most modern armies (*see* Company). In the U.S. cavalry a troop is divided into four platoons.

PLATOON SCHOOL, a work-study-play school organization found in the educational system of the United States. It was originated by William Wirt who started the first school of this type in Bluffton, Ind., in 1902. When he became superintendent of schools of Gary, Ind., in 1907, he organized all the schools of that city on the work-study-play plan. By 1917, 25

American cities had schools so organized, and by 1928, there were 153 cities in 38 States which had over 850 platoon schools.

We begin with the theory that modern cities are extremely bad for children since they deprive them of the healthful work and play which are as essential elements in a child's education as study. The platoon school returns to children opportunities for work and play by providing schools containing not only classrooms but well-equipped shops, science rooms, drawing and music studios, cooking rooms, auditoriums, playgrounds and gymnasiums. The traditional public school is operated on a "peak-load" plan of operation, *i.e.*, on the principle of reserving a school seat for the exclusive use of one child during the entire year. When the children leave these seats to go to shops or playgrounds the seats remain vacant. Under such a plan there are seldom enough seats, playgrounds or shops to accommodate all the children in a city at one time.

Under the platoon plan, on the contrary, all facilities in the school—classrooms, auditoriums, gymnasiums, shops and laboratories—are in use every hour of the day. The school is divided into two parts, each having the same number of classes and each containing all the eight or nine grades. While one of the schools is in classrooms, the other is in special activities, auditorium, playgrounds and gymnasiums. This means that only half the usual number of classrooms is needed. Since the cost of a classroom (1928) is approximately $12,000, this means that in a 30-class school only 15 classrooms are needed, instead of 30, with the result that 15 times $12,000 is released for all other activities in the school. Under this "balanced load," the special facilities add nothing to the cost of the school. According to tests, the children in platoon schools rank as high as the children in non-platoon schools in tests of accuracy; in comprehension and reasoning tests they rank higher.

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PLATT, CHARLES ADAMS (1861–), American architect, was born in New York city on Oct. 16, 1861 and educated in the National academy of design, and in Paris under Boulanger and Lefebre. At first he intended to become a painter and etcher, but the outcome of a visit to Italy was a book, *Italian Gardens* (1892). This explained his adoption of architecture, and his work showed the marked influence of Italian form. He designed many private houses and gardens in addition to public buildings, among the latter being the Maxwell memorial library, Rockville (Conn.) (1917); the Freer Gallery of Art, Washington (D.C.) (1918); the library, Connecticut college for women, New London (1922); the agricultural building, University of Illinois, Urbana (Ill.) (1923); and the Lowell memorial fountain, New York city.

See *Monograph of the Work of Charles A. Platt,* with an introduction by Royal Cortissoz (1913).

PLATTE, a river system of Colorado, Wyoming and Nebraska, tributary to the Missouri river, which it enters immediately north of Plattsmouth, Nebraska, 18 m. below Omaha, in about 41° 3′ N. latitude. Including the North Platte it is about 900 m. long from its headwaters, with a drainage basin for the entire system of 90,000 square miles. The tributaries of the main stream all flow in from the north; the most important being the Loup, and the Elkhorn. The main stream west of Kearney, as well as the North and the South Platte, are extensively used for irrigation.

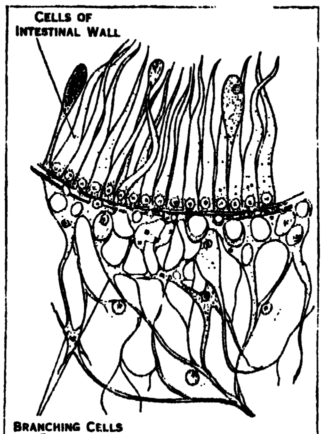
See R. P. Teele, "Water Rights in Interstate Streams," U.S. Dept. of Agric. *Bulletin No. 157* (1905) and J. C. Stevens, *Surface Water Supply of Nebraska* (1909).

PLATTEVILLE, a city of Grant county, Wisconsin, U.S.A., 20 m. from the south-west corner of the State; on Federal highway 118 and served by the Chicago and North Western and the Chicago, Milwaukee, St. Paul and Pacific railways. Pop. (1920) 4,353 (93% native white). It is in a zinc and lead mining region, and is the seat of a State Teachers college. The city was settled about 1827 and incorporated in 1880.

PLATTSBURGH, a city of northern New York, U.S.A., on the west shore of Lake Champlain, is on Federal highway 9 and is served by the Delaware and Hudson railway and lake steamers. Pop. (1920) 10,909 (92% native white); 1928 local estimate 11,800. Plattsburgh is surrounded by beautiful scenery: the broad, island-studded lake in front, with the Green mountains beyond, and on the southern horizon the distant Adirondacks. South of the city, at Plattsburgh barracks (an army post established in 1815), 29,000 reserve officers were trained during the World War, and since 1920 it has been one of the citizens' military training camps, with an enrolment of 3,000 to 4,000 every summer. Cliff Haven (2 m. S.) is the seat of the Catholic Summer School of America, which has an attendance of about 3,000. Plattsburgh is a centre for summer touring and winter sports. Its manufactures (chiefly lumber and various kinds of paper) were valued at $3,285,920 in 1925. Plattsburgh was founded by Zephaniah Platt (1740–1807), who brought a colony from Long Island It was incorporated as a village in 1795 and as a city in 1902. The opening naval engagement of the Revolution (a victory for the British) took place at Valcour island, 5 m. S.E. of Plattsburgh, on Oct. 11, 1776. In the War of 1812 Plattsburgh was the headquarters of the American army on the northern frontier On Sept. 6, 1814, the village was besieged by land, and on Sept. 11, the Commodore Thomas Macdonough defeated the invading fleet.

PLATTSMOUTH, a city of eastern Nebraska, U.S.A., on the Missouri river, at the mouth of the Platte, 21 m. below Omaha; the county seat of Cass county. It is on Federal highway 75, and is served by the Burlington Route and the Missouri Pacific railway. The population was 4,190 in 1920 (86% native white). The city ships grain and cattle, and has large railroad shops, flour mills, broom factories and other manufacturing plants. Plattsmouth is one of the oldest settlements of the State. A trading-post licensed by the U.S. Government was opened here in 1853; a town was platted in 1854; and the city was incorporated in 1855.

PLATYHELMINTHES or **PLATODARIA,** a phylum of invertebrate animals, containing soft-bodied creatures which are bilaterally symmetrical and usually somewhat flattened in shape, and in which there is no true "coelom" or perivisceral cavity and no true (metameric) segmentation. The animals contained in this group (flatworms) are the simplest and probably the most primitive of those in which the tissues and organs of the body are developed from three, instead of two, original embryonic layers.



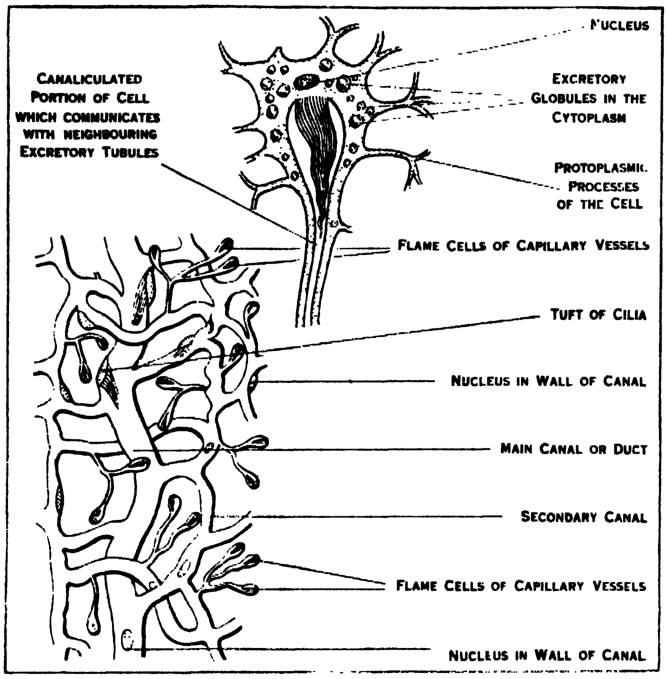
After Kerbert, in "Archiv fur mikroskopischen Anatomie" (Friedrich Cohen)

Fig. 1.—Sectional portion through the body of a trematode (Paragonimus), showing structure of tissues

The external covering of the body is typically an epidermis provided with vibratile cilia These serve partly for locomotion and partly for creating a respiratory current In the adults of certain parasitic groups, the epidermis is replaced by a smooth or spiny cuticle Pigment is commonly present beneath the epidermis in free-living forms, but is usually absent in those which are parasitic. The spaces between the internal organs are for the most part filled up with a kind of loose connective tissue called the parenchyma. The coelom is represented, perhaps, by the cavities of the gonads and of the excretory organs. The musculature of the body is mainly peripheral, consisting of layers of transverse, longitudinal and sometimes also oblique muscle-fibres running through the outer, or "cortical," portion of the parenchyma. These muscles render the body capable of extreme elongation and contraction, and often of surprising variability in shape.

Anterior and posterior ends of the body can usually be distinguished, the animals having a definite direction of locomotion, accompanied by a greater degree of specialization of the anterior extremity. Dorsal and ventral surfaces are also generally distinguishable, the latter being that on which the animal creeps, and on which the oral and genital apertures are commonly situated. In the parasitic flatworms special clinging organs are generally developed, in the form of muscular suckers, often supplemented by chitinoid hooks or spines.

An alimentary canal may or may not be differentiated. When present, it may either be a simple sac-like organ or may be variously branched. With very few exceptions, its only aperture is the mouth, which may be situated subterminally, near the anterior end, or much further back, sometimes even behind the middle of the body. The mouth may be surrounded by an oral sucker, or developed into a protrusible and highly muscular pharynx.


Nucleus
Canaliculated Portion of Cell which communicates with neighbouring Excretory Tubules
Excretory Globules in the Cytoplasm
Protoplasmic Processes of the Cell
Flame Cells of Capillary Vessels
Tuft of Cilia
Nucleus in Wall of Canal
Main Canal or Duct
Secondary Canal
Flame Cells of Capillary Vessels
Nucleus in Wall of Canal

From Lankester, "Treatise on Zoology" (A. & C. Black)

Fig. 2.—Excretory System of a Platyhelminth

Below, diagram of a portion of the excretory system showing branching ducts ending in flame cells. Above, a single flame cell more highly magnified

The main ganglia of the nervous system (the "brain") and the chief sense-organs are generally concentrated towards the anterior end. In addition to tactile papillae or special sensory cilia, "eye-spots" or ocelli are frequently present in free-living forms, and sometimes in the free-living larval stages of parasitic forms. In certain free-living flatworms *statocysts* (sac-like organs containing minute calcareous nodules or *statoliths*) and ciliated pits, probably sensory in function, also occur.

There is no blood-vascular system or haemocoele. The excretory organs consist of a branching system of canals ending internally in "flame-cells." These are minute pyriform structures containing cilia which keep up a constant flickering movement. The main collecting vessels of the system open to the exterior by one, two or many pores.

The Platyhelminthes are, with rare exceptions, hermaphroditic animals, each individual being potentially both male and female. The reproductive system is usually very complex. The male organs consist essentially of one or more (often very numerous) testes, whose ducts are usually connected with a protrusible intromittent organ (penis or cirrus). The essential organs of the female apparatus are an ovary (sometimes multiple ovaries) and a tubular duct communicating with the exterior. The arrangement of the parts of the female system is subject to great variation in different groups. Sometimes the same duct functions in turn as a vagina or fertilization canal, as a uterus or reservoir for fertilized eggs, and as an oviduct by which the eggs reach the exterior. In some cases (most Cestodes) the only communication with the exterior is a vagina, which is connected internally with an oviduct leading from the ovary to a sac-like uterus; but does not serve for the expulsion of eggs. In such forms the eggs are either shed only by the dehiscence of the wall of the uterus and of the body-wall, or by a special (temporary or permanent) birth-pore. In almost all flatworms there is a yolk-gland or vitellarium (often multiple vitellaria), producing yolk-cells which form nutritive material for the developing embryos. The vitellarium, in the most primitive forms, appears to be developed as a sterile portion of the ovary. There is also usually a "shell-gland," possibly concerned in the secretion of the outer covering of the eggs. The ducts of these glands open into the oviduct or into a specialized portion of it called the ootype. The external apertures of the male and female ducts are sometimes separate, but frequently both ducts open into a common "genital atrium," which is often muscular.

The Platyhelminthes are extremely widely distributed, free-living forms occurring in almost every kind of environment—in shallow or deep water, both fresh and marine, and on land—while parasitic forms occur on or in animals of almost every class. The free-living forms usually feed actively on small animals or plants. The parasitic forms show various degrees of modification in habits, some being external parasites and feeding on mucus or other matter derived from the skin of their hosts, while others are internal parasites and feed on partly digested food or on body-fluids. Among the latter class some are without special digestive organs and can only feed by the absorption of liquid nourishment.

The phylum is usually considered to include three main divisions or classes: (1) Turbellaria (including Temnocephalidea), the majority of which are free-living, but some parasitic. This group is probably nearest to the primitive ancestral form. (2) Trematoda (flukes), all of which are wholly or partly parasitic either upon or within other animals. (3) Cestoda (tapeworms), all of which are wholly endoparasitic. *See* Nemertinea, Tapeworms, Trematodes, Turbellaria. (H. A. B.)

PLATYPUS, a remarkable Australian aquatic mammal belonging to the primitive sub-class Monotremata (*q.v.*). The duck-billed platypus (*Ornithorhynchus anatinus*), the only species, is oviparous; two eggs, $\frac{3}{4}$in. long and $\frac{1}{2}$in. wide, each enclosed in a strong, flexible, white shell, are produced at a time. The animal shows many primitive features; there are no true teats in the female, the milk glands being probably modified sweat glands; the body temperature is relatively low. The platypus inhabits the streams and rivers of south-east Australia and Tasmania. About 20in. long, it is clad in short, dense fur of a deep brown above, paler below. There are no teeth in the adult, their purpose being served by horny prominences, two on each side of each jaw, giving the muzzle a very beak-like appearance. In the cheek are capacious pouches. The limbs are short and strong, each with five claw-bearing toes. In the fore-feet, the web extends far beyond the ends of the claws, but it can be folded back on the palm when the animal comes out on to the land. On the heel of the male is a movable horny spur, perforated by a canal which communicates with a poison-gland. The platypus forms deep burrows in the banks, in which it sleeps and brings up its young, the entrance being under water. The food consists of aquatic insects, Crustacea and worms. The animal is nocturnal.

The Platypus (Ornithorhyncus anatinus), an Aquatic Mammal

See H. Burrell, *The Platypus* (1927).

PLATYRRHINE APE, the name applied (in contradistinction to Catarrhine [*q.v.*] to the New World monkeys, on account of the broad septum between the nostrils. *See* Primates.

PLAUEN, a town of Germany, in the republic of Saxony. Pop. (1925) 111,436. Plauen, probably founded by the Slavs, is first mentioned in 1122. It passed under the authority of Bohemia in 1327 and came to Saxony in 1466, remaining permanently united with the electorate since 1569. The manufacture of white goods was introduced by Swabian, or Swiss, immigrants about 1570. It was formerly the capital of Vogtland, or Voigtland, a territory governed by the imperial vogt, or bailiff, and this name clings to the district. The fine Gothic church of St. John, with twin spires, was restored in 1886. The town hall dates from about 1550; and the old castle, Hradschin, is now a law court. Plauen manufactures embroidered white goods and makes lace. It manufactures much of the machinery used in the town and it has a trade in coal, yarn and cattle.

PLAUTUS, TITUS MACCIUS (originally, perhaps, MACCUS; *cf. Asin,* Prol. 11), the great comic dramatist of ancient Rome, was born at Sarsina in Umbria according to the testimony of Festus, who calls him *Umber Sarsinas,* and Jerome. The date of his death was 184 B.C. (Cicero, *Brutus,* xv. 60). The date of his birth depends upon an inference based on the statement of Cicero (*De senectute,* xiv. 50) that he was an old man, when he wrote his *Truculentus* and *Pseudolus.* The latter play was produced in 191 B.C.; hence we get 254–251 B.C. as the approximate date of his birth. The only record that we possess as to his life is that contained in Aulus Gellius iii. 3, 14 (based on Varro), the historical character of which is doubted by Leo (*Plautinische Forschungen,* ch. ii.). The chief fact that emerges is that he left his native Umbrian home and settled as a *peregrinus* at Rome, where, after earning some money and losing it again, he took to writing plays.

The Plays.—His literary activity may well have begun somewhat late in life; for it must have taken him a long time and much hard study to acquire the mastery of Latin and Greek which his dramas attest. The main body of his extant works belongs, so far as can be ascertained from the scanty evidence which we have, to the last 20 years of his life; 206–204 B.C. is the approximate date of the *Miles Gloriosus; cf.* line 211 *seq., quoi bini custodes . . . occubant* (present tense), which alludes to the imprisonment of Naevius. Of the extant plays the *Cistellaria* and the *Stichus* must be associated with the *Miles* as comparatively early works; for the former was clearly produced before the conclusion of the Second Punic War, *see* 1. 201 *seq.;* and the *Stichus* is proved by its didascalia to have been produced in 200 B.C. The *Pseudolus* and the *Truculentus* fall within the last seven years of his life; and the *Trinummus* is later than 194 B.C.; *cf.* 1. 990 *novi aediles.*

The dates of the other extant plays are uncertain. An interesting attempt to place them in chronological order according to the proportion in them of scenes written in lyrical metres and set to music (*cantica*) has recently been made by W. B. Sedgwick (*Classical Review,* xxxix., 1925, p. 55 *seq.*). It is at any rate not improbable that the poet gave greater scope to his musical innovation (*see* below) as his command over language and metres developed and the success of his experiment became assured. The titles of the other extant plays are (in alphabetical order) *Amphitruo, Asinaria, Aulularia, Bacchides* (later than the Epidicus, *see* l. 214), *Captivi, Casina, Curculio, Epidicus, Menaechmi, Mercator* (later than the *Rudens* according to F. Marx and E. Fränkel, but regarded as one of the earliest plays by P. J. Enk in *Mnemosyne,* liii., F. A. Wright in *Broadway Translations,* and W. Beare in *Classical Review* xlii., 1928, pp. 106 and 214 *seq.*), *Mostellaria, Persa, Poenulus, Rudens* (probably first acted 192 B.C.) *Vidularia* (existing only in a fragmentary condition in the codex Ambrosianus). Some of these may possibly be earlier than 204 B.C.; and it seems *a priori* likely that the 35 other Plautine plays known to us only by their titles and a few fragmentary quotations were not all written within the last 20 years of the poet's life.

Indebtedness and Originality.—The plays of Plautus are based on Greek originals of the New Comedy, of which one complete specimen is extant. But Plautus was not a mere translator. This was shown by K. M. Westaway (*The Original Element in Plautus,* 1917), and has been recently demonstrated in detail by E. Fränkel (*Plautinisches im Plautus,* 1922), who calls attention to certain mannerisms as evidence of unmistakable Plautine additions to the Greek texts, and also points out the originality of the Roman in the introduction of a musical element into his plays (*see* below). On the other hand, there are passages in which he does not hesitate to take over from his originals, allusions which can hardly have been intelligible to a Roman audience, *e.g.,* the reference to Stratonicus, a musician of the time of Alexander the Great (*Rudens,* 932); and in the delineation of character we have no reason to suppose that he improved on his models (*cf.* Aul. Gell. ii. 23). Even the bulk of the prologues may be of Greek origin, though certain passages in them must have been added by Plautus, and other passages (e.g., *Casina* 5–20) are post-Plautine. And where Plautus varies his plot on lines of his own by amalgamating the plots of two distinct Greek comedies (*e.g.,* in the *Miles* and the *Poenulus*) the result is generally not happy; the romanization of the plays by way of allusions to towns in Italy, to the streets, gates and markets of Rome, to Roman magistrates and their duties, to Roman laws and the business of Roman law courts, banks, comitia and senate, etc., involves the poet in all the difficulties of attempting to blend two different civilizations. The inconsistency of his attitude is shown by his use, side by side, of the contemptuous expressions *barbarus* (applied to the Romans) and *pergraecari* (applied to the Greeks). In some passages the poet seems to take delight in casting dramatic illusion to the winds (e.g., *Pseudolus,* 720; *Poenulus,* 550).

But as an adapter for the Roman stage Plautus is nothing less than masterly. His command of Latin is such that his plays read like original works, and it may be at least said that some of his characters stand out so vividly from his canvas that they have ever since served as representatives of certain types of humanity, *e.g.,* Euclio in the *Aulularia,* the model of Molière's miser. Alliteration, assonance, plays upon words and happy coinages of new terms, give his plays a charm of their own. "To read Plautus is to be once for all disabused of the impression that Latin is a dry and uninteresting language" (Skutsch, in *Die Cultur der Gegenwart,* 1905). It is a mistake to regard the Latin of Plautus as "vulgar" Latin. It is essentially a literary idiom, based upon the language of intercourse of the Roman society of the day (*cf.* Cic. *De oratore,* iii. 12, 45).

The Characters in his plays are the stock characters of the New Comedy, and they remind us also of the standing figures of the *Fabulae Atellanae* (Maccus, Bucco, Dossennus, etc.). We may miss the finer insight into human nature and the delicate touch in character-drawing which Terence presents to us in his reproductions of Menander, but there is wonderful life and vigour, and considerable variety in the Plautine embodiments of these different types. Their language is often coarse; and there is some deliberate obscenity in it, but not so much as has been discovered by Gurlitt and introduced into his German translation (1920–22). And the careful reader will take note of occasional touches of serious thought (no doubt derived from the Greek originals), as in the enumeration of the ten deadly political sins (*Persa,* 555 *seq.*) and allusions to ethical philosophy (*Pseud.* 972 *seq.; Stich,* 124; *Trin.* 305 *seq.,* 320 *seq.,* 363 *seq.,* 447; *Rud.* 767, 1235–1248, etc.). The *Captivi* is the story of the heroic self-sacrifice of a slave. The *Amphitruo* is a mythological burlesque. But most of his plays depend for their main interest in intrigue, such as the *Pseudolus, Bacchides, Mostellaria.* In the *Menaechmi* and as a subordinate incident in the *Amphitruo* we have a comedy of errors.

Metres.—In the metrical structure of his plays Plautus introduced an important innovation. The New Comedy of Greece had confined itself for the most part to the metres of dialogue: Plautus took the bold step of transposing whole scenes into metres suitable for singing to the accompaniment of the flute (*cantica*); and to other scenes he gave a quasi-operatic character by the use of recitative. But the *cantica* are not mere inserts or accessories, like the songs introduced in the Shakespearean drama; they form integral parts of the action, which would often be unintelligible without them (*see* Fränkel [*op. cit.*] whose theory is a development of that of Leo in *Die plautinischen Cantica und die hellenistische Lyrik,* 1897). The metres employed were, of course, not invented by Plautus; they are of Greek origin and are common to Roman tragedy and Roman comedy; but Plautus gave them a new development and a wider scope. Further light is thrown upon the immediate source of these Plautine metres by J. H. O. Immisch (*Zur Frage der plaut. Cantica,* in *Berichte der Heidelb. Akad.,* 1923). The Plautine metres are wonderfully varied, and the textual critic does well not to attempt to limit the possibilities of original metrical combinations and developments in the Roman comedian.

Reputation.—Plautus was a general favourite in the days of republican Rome. Cicero, though he found fault with the iambics of the Latin comedians generally as *abiecti* "slovenly" (*Orator* lv. 184). admired Plautus as *elegans*, *urbanus*, *ingeniosus*, *facetus* (*De. offic.* i.,29.104). To the fastidious critics of the Augustan age, such as Horace, he seemed rude (*cf. Ars Poetica*, 270–274), just as Addison declared Spenser to be no longer fitted to please "a cultivated age." In another passage (Epist. ii. 1 170–176) Horace accuses him of clumsiness in the construction of his plays and the drawing of his characters, and indifference to everything except immediate success; *gestit enim nummum in loculos demittere, post hoc securus cadat an recto stet fabula talo.* That there are many inconsistencies and signs of carelessness in his work has been proved in detail by Langen. But that he found many admirers, even in the Augustan age, Horace himself bears witness (*ibid.* 1. 58), where he says that Plautus was regarded as a second Epicharmus: *Plautus ad exemplar Siculi properare Epicharmi; cf.* Varro's statement (in Priscian ix. 32), *deinde ad Siculos se applicavit.* It is possible that Plautus may have been working on the lines of the old comedy in the tell-tale names which he is so fond of inventing for his characters such as Polymachaeroplagides (*Pseud.* 988), Pyrgopolinices (*Mil.* 56), Thesaurochrysonicochrysides (*Capt.* 285)—names which stand in remarkable contrast to the more commonplace Greek names employed by Terence.

In the middle ages Plautus was little regarded, and 12 of his plays (*Bacchides—Truculentus*) disappeared from view until they were discovered (in the ms. called *D*) by Nicholas of Treves in the year 1429. But after the revival of learning Plautus was reinstated, and took rank as one of the great dramatists of antiquity; *cf.* Shakespeare, *Hamlet*, II., ii., 420, where Polonius says "The best actors in the world . . . Seneca cannot be too heavy nor Plautus too light."

Influence on Modern Literatures.—A comprehensive view of the widespread influence of Plautus on modern literatures is given by Reinhardstoettner, *Spätere Bearbeitungen plautinischer Lustspiele* (1886). Many adaptations for the Italian stage were produced between the years 1486 and 1550, the earliest (the *Menaechmi*) under the direction of Ercole I., duke of Ferrara. From Italy the practice spread to France, Spain, England and other countries.

Of English plays the interlude called *Jack Juggler* (between 1547 and 1553) was based on the *Amphitruo*, and the lost play called the *Historic of Error* (acted in 1577) was probably based on the *Menaechmi;* Nicholas Udall's *Ralph Royster Doyster*, the first English comedy (acted before 1551, first printed 1566), is founded on *Miles Gloriosus;* Shakespeare's *Comedy of Errors* (about 1591) is an adaptation of the *Menaechmi;* and his Falstaff may be regarded as an idealized reproduction or development of the braggart soldier of Plautus and Terence—a type of character which reappears in other forms not only in English literature (*e.g.*, in Shakespeare's Parolles and Ben Jonson's Captain Bobadil) but also in most of the literatures of modern Europe. Shakespeare's *Taming of the Shrew* has been influenced in several respects (including the names *Tranio* and *Grumio*) by the *Mostellaria.* Ben Jonson produced a skilful amalgamation of the *Aulularia* and the *Captivi* in his early play *The Case is Altered* (written before 1599). Thomas Heywood adapted the *Amphitruo* in his *Silver Age* (1613), the *Rudens* in his *Captives* (licensed 1624), and the *Mostellaria* in his *English Traveller* (1633). Dryden's *Amphitryon or the two Sosias* (1690) is based partly on the *Amphitruo*, partly on Molière's adaptation thereof; Fielding's *Miser* (acted 1732) on Molière's *L'Avare* rather than on the *Aulularia*, and his *Intriguing Chambermaid* (acted 1733) on Regnard's *Le Retour imprévu* rather than on the *Mostellaria.*

BIBLIOGRAPHY.—Standard Texts and Editions with Notes: Texts by Goetz and Schoell (*editio minor*, 1893–1907), by Leo (1895–96), by Lindsay (1904–05). With notes: *Captivi*, by Lindsay (1900), by Brix (6th ed., 1910); *Menaechmi*, by Brix (5th ed., 1912); *Miles* by Lorenz (2nd ed., 1886), by Brix (3rd ed., 1901); *Mostellaria* by Lorenz (2nd ed., 1883), by Sonnenschein (2nd ed., 1907); *Pseudolus* by Lorenz (1876); *Rudens* by Sonnenschein (1891, ed. min., 1901); *Trinummus* by Brix (5th ed., 1907); other plays in Macmillans Classical Series and the Pitt Press Series. Lexicon: Gonzalez Lodge's *Lexicon Plautinum* (nearing completion and indispensable). Syntax: Lindsay, *Syntax of Plautus* (1907): Metre and Prosody: Lindsay, *Early Latin Verse* (1922); Vollmer, *Römische Metrik* (1923); and *Ueber die sogenannte Iambenkürzung* (1924); Sonnenschein in *What is Rhythm?* (1925, ch. vi.). E. Fränkel's *Iktus und Akzent im lateinischen Sprechvers* (1928) is an attempt to show that in the dialogue metres, as distinct from the metres set to music, the verse-stress (*ictus metricus*) nearly always coincides with a genuine speech-accent, or at any rate corresponds to some modification of accentuation or intonation such as was heard, or might have been heard, in ordinary Roman speech. Translations: English prose by P. Nixon in the Loeb Series (1916–24; 2 vols. still to come); English verse by Wright and Rogers in *Broadway Translations*—select plays (1923); German verse, by C. Bardt in *Römische Komödien* (1909, etc.).

PLAYA (a Spanish word meaning "shore"), the name applied in America to a level plain formed of the deposits of a river which has no outlet to the sea or a lake. If at seasons of high water a river floods any area and temporarily converts it into a lake, which subsequently dries up in hot weather, the tract thus left dry is called a playa. The barren Black Rock desert in north-western Nevada, about 100m. in length by 15 in breadth, is typical.

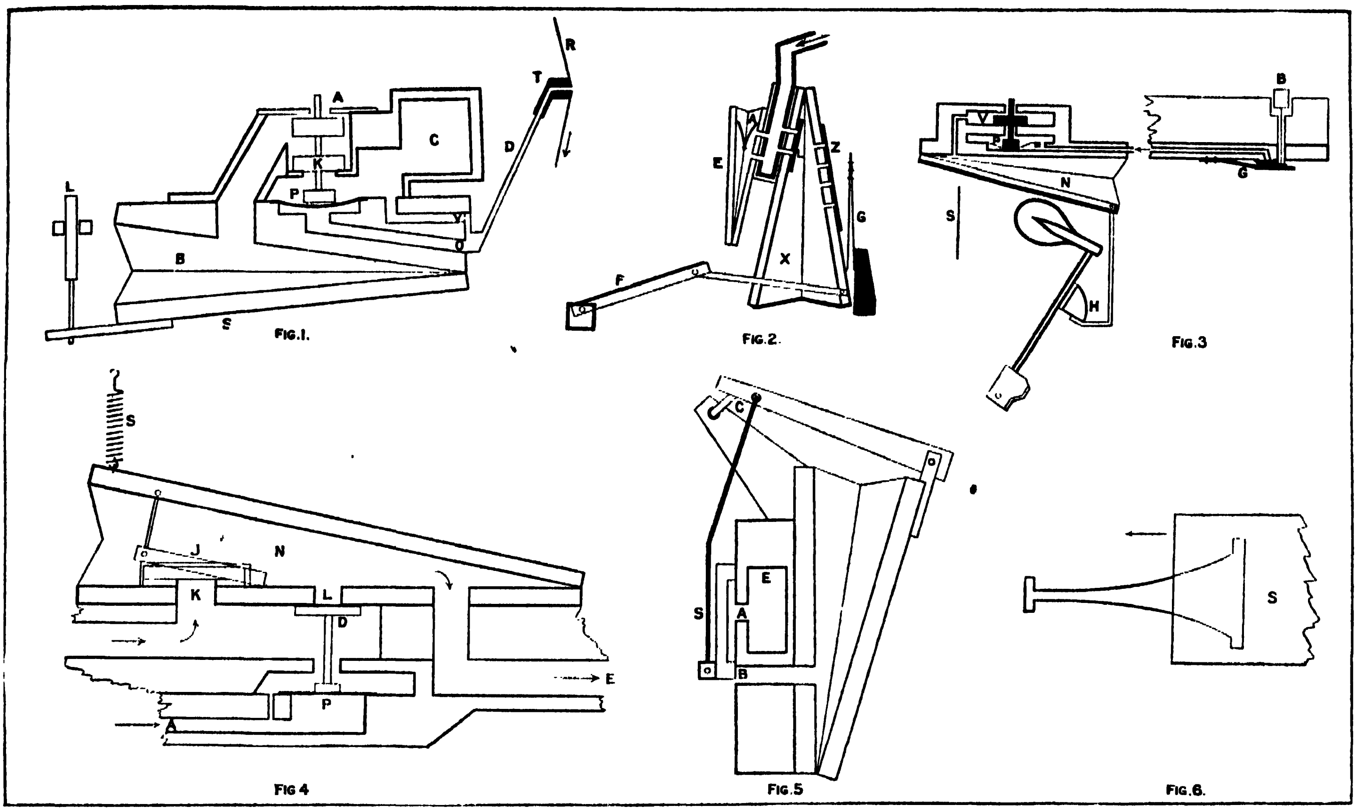
PLAYER-PIANO, a piano equipped with a mechanical device for automatically playing written music or for reproducing the playing of a pianist. All types of player-piano mechanism are operated by utilizing the difference between external and internal air pressures. In fig. 1, the tracker-bar, T, with its 88 holes, is represented as being closed by the paper roll, R, which lies closely against it. Some of the air has been extracted from the duct, D, and from the chamber, C, by means of an air-exhaust to which they are connected. There is a very tiny vent, V, which allows air from the tracker duct to leak into the chamber. A disk, K, closes the chamber from the outer air, being held down because the air in C, is at a lower pressure than normal. The pneumatic, B. is full of air at normal atmospheric pressure and is open to the external air by means of the port, A.

Should a hole in the paper come into line with any hole in the tracker-bar, the external air rushes into the duct and lifts the pouch, P, which is simply a circular piece of soft kid about ¾in. in diameter, and bigger than K. Hence it lifts K, connecting the pneumatic with the partial vacuum, C, and disconnecting it from the external air by closing the port A. The air in B spreads to C and, the external pressure on the surface, S, being greater than the reduced pressure inside, the pneumatic collapses suddenly, the movable leaf rising and lifting with it the pilot, L, which operates the piano action.

The pneumatic remains collapsed until paper again blocks the hole in the tracker-bar. The air in D then leaks through into C and can no longer hold up the pouch, which falls back into position and allows K to close the chamber C again, at the same time opening the pneumatic to the external air at A. The external and internal pressure on S now being the same, the pneumatic re-inflates and allows the pilot to drop back into position.

In the days of heavy and clumsy valves it was difficult to provide the necessary power to lift them rapidly without hard pedalling and consequent loud tone. To overcome this defect the more expensive player action was provided with an additional (or primary) valve of light construction, easily lifted by the inrush of air when a hole was opened on the tracker-bar. Its lifting admitted air to the other and heavier valve, through the port O, operating the striking pneumatic as previously described. Both single and double valve systems are still in use.

The interior of the player action is maintained in a steady state of reduced pressure by forcing the pedal, F, to open the exhaust, X (fig. 2). This allows all the interior air to spread itself into X past L, a flat strip of well-tanned leather, lying over holes. A fan spring, G (about 12lb. in strength), then closes the exhaust, expelling the air via another flap valve, Z. A strong spring, A, is always trying to open the equalizer, E, but is prevented from so doing when the external air pressure is much greater than the reduced pressure inside. When, however, there is not much difference between the external and internal pressures, the spring can open and in so doing allows air to spread into it from the interior. The effect is to reduce the internal pressure



MECHANISM OF THE PLAYER-PIANO. THE FIGURES AND LETTERS ARE EXPLAINED IN THE TEXT

once more to such an extent that the equalizer begins to collapse. Its constant to-and-fro motion enables a steady amount of reduced pressure to be maintained in the interior channels, despite unsteady working of the pedals.

Controls.—The simplest method of operating the "soft" and "sustaining" pedals is to connect the ordinary mechanism of the piano, by suitable levers, to finger controls in front of the keyboard. Many manufacturers prefer to control the distance from the hammers from the strings as shown in fig. 3. A button, B, opens a gate, G, when pressed down. This admits air to a pouch, P, which lifts the valve lying above it, and puts the pneumatic, N, into communication with a partial vacuum, V, thus collapsing it and causing it to lift the hammer rail, H, which softens the tone by giving the hammerhead less distance to travel towards the string, S.

A similar device withdraws all the dampers from the strings. This being a heavier task than shifting the hammers, a larger pneumatic has to be employed, and two valves instead of one. Music rolls are provided with an additional hole at the left-hand edge, which works the lifting of the dampers, if desired.

Change of power, in addition to the means above described, is provided by varying the strength of the blow given to the hammer. Fig. 4 shows how the normal amount of reduced air is altered by interposing a pneumatic, N, between the main exhaust, E, and the small playing pneumatics. Pressing a button (as in fig. 3), air is allowed to enter at A, the pressure from which lifts the pouch, P, and with it the valve, D. This closes the large hole, L, and leaves only the aperture, K, over which lies a knife-cutter valve, J, so called because it closes like the blade of a pen-knife. The spring, S, is of such strength that it governs the amount of air passing through to the bellows, hard pumping closing N and therefore closing the aperture K and preventing loud playing.

A slight alteration of fig. 4 would give a fair representation of the automatic Accenting Device, which is worked from marginal perforations in the music roll. The valve disk, D, is moved to the other side of the hole, L, keeping it normally closed and softening the tone until a marginal perforation allows air to rush towards P. The pouch lifts the valve, opens L and accents the note.

The pedals also provide sufficient power to work the spool which draws the music roll over the tracker-bar. Five pneumatics of the type shown in fig. 5 are fixed at equal angular distances upon a crank-shaft, C, each one collapsing in turn and so driving the shaft round steadily. Collapse is effected when the hollow slide, S, is covering both of the ports A and B, for the pneumatic is then in direct communication with the main exhaust, through E. As the crank-shaft is thus moved round, the slide is raised, and no longer covers both ports. External air is admitted to the pneumatic, and the collapse of one of its neighbours provides the power to lower its slide and again get into communication with the main exhaust.

All communication between motor and exhaust is by way of a governor pneumatic; powerful pedalling tends to collapse it, but directly this happens a knife-valve partly closes the passage-way (as in fig. 4), and thus prevents the motor from "racing." Variation in tempo is secured by deliberately altering the size of the passage-way within an enclosure known as the Tempo Box. The shape of the slot is usually as shown in fig. 6, over which passes a slide, S. When half the area of the slot is covered, the speed of the motor is half its maximum, and so on, the slide being worked mechanically from the control board.

The holes in the paper roll being so close together, it is essential that they should track correctly, despite the effects of wear and weather. Correct tracking is controlled in ways which vary in detail, but usually depends upon the action of two pneumatics, kept under exhaust. Holes in the tracker-bar are so placed as to be uncovered when (and only when) the roll goes to one side, letting air into one of the pneumatics and causing it to open slightly, taking with it either tracker-bar or spool.

Reproducing Pianos.—The "reproducing" instruments are in a separate class, designed to reproduce faithfully all the shades of tempo and expression made by well-known pianists. All control is rightly withdrawn from the operator when using the specially cut rolls, but the same instrument may be used for ordinary rolls by putting the reproducing mechanism out of action. Additions to the normal player mechanism are mostly for the purpose of controlling more completely the comparative loudness or softness of individual notes. To do this effectively it is necessary to have as many grades of power as possible, to include smooth crescendo as well as sforzando effects.

The Ampico mechanism alters the size of the main passage-way (and hence the power) by means of a regulator valve, which is attached to a lever, controlled by a set of pneumatics under vacuum (three small "intensity" pneumatics above, balanced by a large "spring" pneumatic beneath). When marginal perforations connect up to the valves of the "intensity" pneumatics, these lift and allow the pneumatics to fill with air, thus exerting an up-push on the lever, raising the regulator valve and increasing the size of the passage-way. As these pneumatics lie along the lever, their lifting power depends upon position, those furthest from the fulcrum end being the most effective. When it is necessary for an intensity pneumatic to collapse again, another marginal perforation, connecting up to a "cancel" valve, admits air and allows this to happen. Further marginal perforations are provided, one for slow crescendo, and the other for fast crescendo, each connecting up to the same crescendo pneumatic, but in the latter case two ways are open for the air to escape, making the pneumatic collapse quickly. For "brilliant" or extra powerful performance, the Ampico can be switched over so as to close the slight "in-leak" provided on one of the three pumpers of the power mechanism. The whole system then works at maximum power. For subdued performance the main passage-way is blocked by a disk, operated pneumatically from a switch in the spool-box.

The Angelus Artrio system employs thirteen expression openings, all leading from the interior to the exhaust pumps. Five of these are in the controlling governor, and the others in the treble and bass sections. They vary in size from tiny vents to a large "melody" opening, and all air must pass through one or more openings on its way from tracker-bar to main exhaust. In addition, there is an "in-leak" as on the Ampico, but the Angelus system works it from the tracker-bar. When a perforation appears against the second hole from the left-hand side, the "in-leak" is closed and an increase of power results.

The Duo-Art (Aeolian Company) is essentially a theme and accompaniment expression arrangement, the former being at a higher dynamic power than the other. Each has a knife-valve control of the passage-way, operated by a set of four pneumatics, varying in their amount of possible collapse. In this way six variants of power are obtained. There is also an "in-leak," automatically closed by another knife-valve so as to get maximum power when the passage-way is already nearly full open.

The Welte-Mignon is worked by suction fan instead of the usual pumpers. Its expression unit consists of a governor bellows, held open by a coiled spring. This controls the position of a conical valve in the passage-way, and is itself automatically responsive to the amount of work being done at any moment within the pneumatic system. The expression pneumatic, which also works the same conical valve, is operated from the tracker-bar, and can act slowly or quickly according to the perforations in operation. (S. A. H.)

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Value of the Player-piano.—The player-piano in its modern perfected form enjoys the whole-hearted support of musicians. In schools it has proved invaluable, while in musical colleges and academies it is utilized as a means of familiarising students with the interpretations of the greatest performers.

PLAYFAIR, JOHN (1748–1819), Scottish mathematician, was born at Benvie, Forfarshire, where his father was parish minister, on March 10, 1748. He was educated at home until the age of 14, when he entered the University of St. Andrews. He was ordained, and succeeded his father in the parish of Benvie, but continued his scientific studies. In 1785 he succeeded Dugald Stewart in the chair of mathematics at Edinburgh, which he exchanged in 1805 for that of natural philosophy. In 1795 he published his *Elements of Geometry,* which later passed through many editions. He enunciated the axiom now known by his name, viz., that two intersecting straight lines cannot both be parallel to the same straight line. He was elected F.R.S. in 1807. He died in Edinburgh on July 20, 1819.

His other publications include: *Illustrations of the Huttonian Theory of the Earth* (1802); *Outlines of Natural Philosophy* (2 vols., 1812–16). His collected works, with a memoir by J. G. Playfair, were published at Edinburgh (4 vols. 1822).

PLAYFAIR, LYON PLAYFAIR, 1ST BARON (1818–1898), was born at Chunar, Bengal province, on May 21, 1818, and educated at St. Andrews, Glasgow, Edinburgh, University College, London, and under Liebig at Giessen, where he took his doctor's degree. Playfair translated into English Liebig's *Chemistry of Agriculture.* From 1841–42, he was chemical manager of the Primrose print-works at Clitheroe, and in 1843 was elected honorary professor of chemistry to the Royal Institution of Manchester. Soon after he was appointed a member of the Royal Commission on the Health of Towns, a body whose investigations may be said to have laid the foundations of modern sanitation. In 1845 he was appointed professor in the new School of Mines, and chemist to the geological survey, and thenceforward was constantly employed by the public departments in matters of sanitary and chemical inspection. For his services as special commissioner of the 1851 Exhibition, he was made C.B. From 1856 to 1869 he was professor of chemistry at Edinburgh University. In 1868 he was elected to represent the universities of Edinburgh and St. Andrews in parliament, and retained his seat till 1885, from which date until 1892 he sat as member for Leeds. In 1873 he was made postmaster-general, and in the following year, after the dissolution of parliament, was made president of a commission to inquire into the working of the civil service. Its report established a completely new system, known as the "Playfair scheme." From 1880, when Gladstone returned to power, till 1883, Playfair acted as chairman of committees. In 1892 he received a peerage, and in 1895 the G.C.B. He died in London, on May 29, 1898, and was buried at St. Andrews. He published a volume, *Subjects of Social Welfare.*

A memoir by Sir Wemyss Reid was published in 1899.

PLAYFAIR, SIR NIGEL (1874–), actor and theatrical manager, was born in London on July 1, 1874. Educated at Harrow and at University college, Oxford, he acted with the Oxford University Dramatic Society. For some time he practised as a barrister. On July 30, 1902, he made his first appearance as a professional actor at the Garrick theatre, London, in "A Pair of Knickerbockers." He was chiefly associated with the Lyric theatre, Hammersmith, London, the management of which he assumed in 1919. Among his most famous productions at this theatre were John Drinkwater's *Abraham Lincoln* (1919) and the revival of Gay's *Beggar's Opera* (1920) which ran for over three years. He published *The Story of the Lyric Theatre, Hammersmith* (1925), and other works. He was knighted in 1928.

PLAYFORD, JOHN (1623–*c.* 1686), English musical publisher, was born at Norwich. From 1653 he was clerk to the Temple church, and from his shop in the Inner Temple issued most of the English music of his day. Of his own compositions the chief are numerous psalm tunes, the popular *Introduction to the Skill of Musick* (1654, 19 ed. 1730) and *The Dancing Master* (1650), a collection of airs for the violin used for country dances which constitute an invaluable treasury of English national tunes.

See F. Kidson, *British Music Publishers.*

PLAY IN ANIMALS. Play is illustrated by kittens with their ball, puppies and their sham-hunt, lambs and their races, monkeys and their "follow-my-leader." There are often sham-fights among birds which seem to be entirely playful, besides exhibitions of flying powers that have no direct usefulness. For it is one of the criteria of play that it is not directly useful. Play is not work, though it may be as strenuous and may lead to exhaustion; it is not mere exercise, though, perhaps, it exercises best; it has no deliberate (or, in animals, perceived) end, for the sake of which it is played, yet it may be almost indispensable if the animal is to attain to the full use of its powers. Play is not necessarily social, for many a kitten plays alone; and it is not necessarily competitive, though rivalry may give it zest. Its keynote is its anticipation of modes of activity characteristic of adult life.

Play is well illustrated by many young carnivores, such as cats, dogs, foxes, otters and bears; by many young ungulates, such as lambs, kids, calves and foals; by most monkeys, and by less familiar cases like young squirrels and water-shrews. Yet it cannot be said to be a general feature in the youthful life of mammals. It is not common among birds; it is only hinted at in reptiles, amphibians and fishes; and it is at most incipient among backboneless animals. This raises the question why a playing period should be interpolated in the life-history of only a small minority. There must be some particular biological advantage in play, yet one which only certain types have been able to secure.

Uses of Play.—The poet Schiller suggested that animal play is an expression of overflowing energy. But while this theory has its grain of truth, it is far too simple. Thus there are many young animals with abundant vigour that never play; and it is well known that a thoroughly tired animal, such as a dog, may turn in a moment from fatigue to play, as children often do. Moreover, half the problem is that different types of mammals play in characteristic or specific ways.

Schiller's theory of play was re-expressed by Herbert Spencer with the important additional suggestion that imitation accounts for the particular form that the playing takes. The physiological condition of play is superfluous energy, but imitation defines the channel of expression. Young creatures mimic in play what they see their seniors doing in earnest. Here again there is some truth, and corroboration may be found in the imitativeness of certain forms of playing in children. But Spencer's theory will not cover the facts. Thus an isolated young animal, such as a kitten, will play, and will play true to type, provided that an appropriate liberating stimulus, apart from imitation, is supplied at an appropriate time. But if a kitten reaches a certain age—usually about two or three months—without having had any experience of mice, it will not afterwards show any "mousing instinct," nor any capacity for playing with a mouse.

A third idea has some relevance, namely the close correlation between pleasant emotions and bodily movements. It is a familiar fact of experience, elaborately studied by the physiologists and psychologists, that pleasant feelings reverberate in various parts of the body, such as the heart, lungs, larynx, food-canal and bladder. The correlation of emotional excitement and activity of the suprarenal bodies is well known. But to the internal movements there may be added movements of the body as a whole, and these will be naturally specific for different types. The child dances with joy; the otter cub gambols exuberantly. This simple movement-play may be a useful safety-valve, but it is also a natural expression of overflowing *joie-de-vivre.*

To Karl Groos we owe the illuminating suggestion that play is important as an irresponsible apprenticeship to the subsequent business of life. It is the young form of work, and this accounts for its specificity. The young carnivore has its sham hunt, the young ungulate its amateurish race, neither involving serious responsibilities. Under the shelter of parental or communal care the playing animal educates powers essential in after-life, and is afforded opportunities without the serious consequences involved whenever the struggle for existence sets in keenly. As Groos puts it, animals do not play because they are young; they continue young in order that they may play. No doubt non-playing young animals also educate their capacities, but the point is that the interpolation of the play-period is an additional advantage which some plastic and well-endowed creatures have been able to secure for themselves. It is interesting that most of the mammals man has succeeded in domesticating are playing mammals.

Another aspect of the play-period is that it affords opportunity for testing new variations before the struggle for existence sieve becomes too fine in the mesh. Play affords elbow-room for new departures, and its value is particularly clear when the adult life is very varied, like an otter's, demanding plasticity and resourcefulness. Here there is a marked contrast between games, which are restricted to mankind, and play, which children share with young animals. For the game has its rules and demands self-subordination, whereas play is spontaneous and allows of idiosyncrasies and experimentation. From the biological point of view it is clear that human games cannot fulfil all the functions of play.

According to Groos there is no general "instinct to play"; it is enough to suppose that each type of playing animal has its inborn or instinctive system or pattern of predispositions towards particular types of adult activity, and that the young are peculiarly sensitive to liberating stimuli. Play implies not only susceptibility, but precocity and plasticity. It secures a certain freedom for initiative before habituation sets in. And this, as has been said, is of especial value when the adult life demands considerable versatility. In such cases, the animals that play best are also likely to work best.

Types of Play.—If play is anticipatory of future work, the different kinds of play will correspond to the chief activities of adult life. (*a*) Many forms of play are of the nature of experiments in locomotion, as in aimless racing, rival jumping, riotous gambolling and feats of climbing or of flying. Here one pictures the behaviour of lambs, kids, calves, young antelopes, young chamois, foals, young squirrels and young monkeys. (*b*) On another line is sham-hunting, in which the young animal chases some moving object irrespective of all utility. A leaf blown by the wind or a ball of grass will pull the trigger as effectively as a small animal. The mother sometimes aids and abets, and here play may coalesce with education (*see* ANIMALS, EXPERIMENTS ON). The kitten's play with the mouse, often absurdly misinterpreted as "delight in torture," is paralleled in many other young carnivores. It is justified in the present by the repetition of pleasurable excitement, and in the future by the increased dexterity it develops. When the mouse-play is exhibited by cats of mature years, and apart from their education of their kittens, it is probably a relapse into youthful play, illustrated less poignantly in some other adults. (*c*) A third form of play is the sham-fight, familiar in puppies. It has been described among lions, tigers, hyenas, wolves, foxes, bears and other carnivores; among lambs, kids, calves, foals, antelopes and other ungulates. It is also common among birds. Care must be taken to keep the sham-fight distinct from the combats of rival males, the first hints of which may begin early, as in bull-calves. And even apart from sex, it is not always easy to distinguish the sham-fight from serious combativeness. In his description of the behaviour of two young gluttons, Brehm says that nothing could be more playful, they were hardly at a rest for a minute, but every now and then the note of earnest was struck. Very curious, considering the level at which they occur, are the so-called sham-fights which several good observers have described among ants. There is energetic wrestling and the like, but no discharge of poison or actual wounding. (*d*) Perhaps one may recognize another type which may be called playful experiment, when animals test things, often pulling them to pieces; or test themselves, often performing interesting but useless feats; or test their neighbours, discovering how they will respond to sundry provocations. The difficulty is to distinguish these playful experiments from the ways in which many well-endowed young animals feel their way about in their environment. But Hamerton describes how his young goats would spend hours in jumping in and out of a basket, or would try to upset the artist by getting under his seat, or would tease the big dog to the limit of his endurance.

Along this line the subtlest forms of play are found in apes, where experimenting may go far, and sometimes become sheer mischief. Chimpanzees often show what looks like delight in being a cause, and an entirely useless activity may be repeated over and over again. Thus a chimpanzee will entice a hen with bread, and pull the reward away at the last minute, repeating the trick many times with evident gusto. Or it will attract a hen close to the cage and then give her a sudden poke with a stick when she is preoccupied with her food. This seems almost like a joke.

Of interest are those cases where playing or something like playing is continued long after youth is past. This is familiar in domestic dogs, but is also exhibited in natural conditions, for instance by the otter. This extension of play may be sometimes associated with the mother's habit of playing with successive litters of young ones year after year. But this interpretation does not apply to all cases, for instance to the communal playing of full-grown penguins on the sea-ice. Thus Murray Levick has described the diving play in which the succession of birds may be so rapid "as to have the appearance of a lot of shot poured out of a bottle into the water." A favourite activity was to board an ice-floe till it would hold no more, and get carried by the tide to the lower end of the rookery, where every bird would suddenly jump off and swim back against the stream to catch a fresh floe and get another ride down. An adult snake-bird (*Anhinga*) has been seen playing catch with twigs, an activity obviously correlated with its dexterity of head and neck in catching fish. Many birds have flight games; the "shooting" and tumbling of rooks and herons, and the turning upside-down of ravens may be specially mentioned. It seems impossible to restrict the idea of play to youth.

But in general play is a mode of behaviour characterizing the youthful period of certain well-endowed animals, a precocious exhibition of activities more or less anticipatory of those characterizing adult life, but not in themselves of direct utility. Its biological significance is partly as a safety-valve for overflowing energy, partly as an early expression of imitativeness, partly as a correlate of pleasant feelings, but mainly as an irresponsible apprenticeship to adult activities and an opportunity for testing new departures, especially in habit.

Restrictions of Play.—Since these characteristics of typical play are tolerably well-defined, it is undesirable that the concept should be blurred by a vague and loose application of the term. The following restrictions may be suggested: (1) The term play should not be used for the idle movements of animals, such as insects and fishes, unless there is evidence that these are serving as an apprenticeship. Gregarious swimming on the part of cuttlefishes and fishes, gregarious flying on the part of insects and birds, may have no utility, and yet hardly deserve the name of play.

(2) It is undoubtedly difficult to draw the line, but it seems useful to try to exclude from typical play all activities bound up with sex-display or courtship. For while these resemble play in being artistic and spontaneous expressions of individuality, they have an immediate outcome: they serve to arouse sex interest and sex desire, whereas typical play never has any immediate reward. If it seem impossible to draw a line between play and display, it might conduce to clearness if the word, sex, were used as a prefix. Thus one might use some phrase such as courting dance for many of the extraordinary displays that birds make at the breeding season (*see* BIRD, *Reproductive Habits;* COURTSHIP OF ANIMALS). W. H. Hudson portrays the dance of the cock-of-the-rock (*Rupicola*) of tropical South America: "A mossy level spot of earth surrounded by bushes is selected for a dancing-place, and kept well-cleared of sticks and stones; round this area the birds assemble, when a cock-bird, with vivid orange-scarlet crest and plumage, steps into it and, with spreading wings and tail, begins a series of movements as if dancing a minuet; finally, carried away with excitement, he leaps and gyrates in the most astonishing manner, until, becoming exhausted, he retires and another bird takes his place." This strikes a note quite different from that sounded in the races of lambs and kids, wild foals and asses, or "tag" and "follow my leader" among monkeys.

(3) It is part of the essence of play that it is not directly useful, but has a prospective value in educating efficiency. But not a few animals with abundant spare energy and initiative are known to indulge in occasional adventures which, though they can hardly be called other than playful, have no prospective meaning. Some of the experiments of apes, to which we have already referred, may illustrate this kind of behaviour, and should perhaps be called tricks rather than play. True play is characteristic of a species and is neither occasional nor individual. A naturalist relates that on one occasion, when botanizing on the Alps, his dog ceased to follow him on the graduated path, and was seen to choose a more direct slope of hard snow. There he lay down on his back, folded his legs and slid down like a toboggan. At the foot he looked up at his astonished master and wagged his tail! No conclusion can be based on single instances, however well documented, but we cite this case as an instance of probable misinterpretation. The observer supposed that the dog had thought out a short cut—an unnecessarily generous view; others have called it a piece of play. But the probability is that it was a casual adventure, such as may be reasonably put to the credit of many a well-endowed animal. Similar instances are known at much lower levels of intelligence. The ecological concept of animal play is most useful when employed in the strictest sense, as already defined. (*See* ANIMAL BEHAVIOUR; PSYCHOLOGY, COMPARATIVE; SEXUAL SELECTION.)

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(J. A. TH.)

PLEADING: *see* PRACTICE AND PROCEDURE.

PLEASANTVILLE, a city of Atlantic county, New Jersey U.S.A., 5 m. W.N.W. of Atlantic City; served by the Pennsylvania and the Reading railways. Pop. (1920) 5,887.

PLEASURE: *see* FEELING, PSYCHOLOGY OF; HEDONISM ETHICS.

PLEBISCITE, a term borrowed from the French for a vote of all the electors in a country or given area taken on some specific question. The most familiar example of the use of the plebiscite in French history was in 1852, when the *coup d'état* of 1851 was confirmed and the title of emperor was given to Napolean III. Its essential characteristic, as distinguished from the referendum (*q.v.*), is this:—A plebiscitary vote decides a specific question, *ad hoc* and *pro hac vice*. It is not, as in the case of the referendum, a normal method or procedure of voting applied on a general system to certain classes of legislation. It is sometimes used in England to decide questions of municipal rates or other local questions, and extensively in the Dominions and the United States on certain local or State questions. In Europe its use has been almost wholly political and national.

In that sense it is a method of ascertaining the general desire of the inhabitants of a given territory or area. As a means of settling the destination of populations and territories, this method was first used in the French Revolution to defend the wholesale annexations of territory made by the conquering French Republic, and subsequently by Napoleon I. It was revived by Napoleon III, and applied (successfully for him) in the case of Nice and Savoy, and (successfully for Victor Emmanuel) in the duchies of north Italy during the years 1859–60.

The Peace Conference of 1919 proposed the taking of 17 plebiscites to settle difficult national questions of which eight were actually held. Of these the Turkish plebiscite in Transcaucasia was a farce. Others, which decided the fate of Allenstein Marienwerder, of the Burgenland, of Klagenfurt, the economic destiny of Luxembourg, the attribution of the northern and southern zones of Slesvig, and the partition of Upper Silesia had substantial and important results, which are noted elsewhere under the individual articles. The Versailles Treaty provided for a plebiscite of the Saar district in 1935 to decide the future of the region.

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PLEBS, the "multitude," or unprivileged class in the early Roman state (from the root *pleo*, seen in Latin *plenus*, fill; *cf.* Gr. πλῆθος). For the origin and history of this order *see* PATRICIANS. Its disqualifications were originally based on descent, but after the political equalization of the two orders these ceased.

PLECOPTERA (Gr. πλέκος plaited, and πτερόν, a wing) is that order of insects which comprises the stone-flies: by some authorities they are termed Perlaria from *Perla*, the principal genus. Stone-flies are dull coloured insects, either black, brown or grey, or in some species green. They are poor fliers and do not wander far from water where their early stages are passed. Their habitation is the margins of streams and lakes, especially in hilly or rocky districts and they are usually found resting on stones, palings or tree-trunks, or crawling about over stones or plants: the green forms frequent bushes or other herbage and are difficult to detect. Fewer than 500 species are known and these are classified into seven families: about 30 species inhabit the British Isles and a considerably larger number is found in the United States. The richest fauna is found in the southern hemisphere and the earliest forms are confined to the Australian region and Chile.

Stone-flies are soft-bodied insects with long thread-like antennae: the wings are membranous, folded flat over the back in repose and the hind pair is usually the largest with a plicated posterior lobe. The mouth-parts are weak and of the biting type, the tarsi are three-jointed and the body is generally terminated by long, many-jointed tail-feelers. These insects derive their name from the fact that their nymphs are often common beneath stones in the beds of streams. The females discharge their eggs in masses into the water: metamorphosis is incomplete and the nymphs only occur in clear, unfouled streams or lakes, not in stagnant water. Some are carnivorous, while others feed upon organic particles of various kinds. In form they resemble the perfect insects very closely except for the absence of wings: they are provided with lateral tufts of abdominal tracheal gills or with a terminal group of these organs around the anus. When fully grown the nymph crawls out of the water and the imago emerges. A few Plecoptera in the fossil condition are met with in the Upper Jurassic rocks of Europe, and in the Lower Permian of Kansas.

The nymphs serve as food for certain fishes, such as trout, and are in that respect valuable. The species *Taeniopteryx pacifica*, has been recorded as damaging the buds of fruit trees in Washington State.

Further information on these insects will be found in works on aquatic insects (*see* Insects), while for the British species *see* papers by K. J. Morton in *Trans. Entomological Soc. London* (1894, 1896). The North American species are dealt with by J. G. Needham and C. P. Claassen, *The Plecoptera or Stone-Flies of North America* (1925), and for the general classification of the order *see* R. J. Tillyard, *Canadian Entom.* (vol. liii., 1921). (A. D. I.)

PLECTRUM, a small contrivance, made of metal, wood or some other suitable material, and used as a substitute for the finger in plucking the strings of musical instruments. In ancient times the strings of the lyre were sometimes so plucked, while later the lute was similarly played, as are the mandolin and zither to-day; the same term being applied also to the quills and bristles of the harpsichord and spinet.

PLEDGE or **PAWN,** in law, a "bailment of goods by a debtor to his creditor to be kept till the debt is discharged" (Jones on *Bailments*). The term is also used to denote the property which constitutes the security. Pledge is the *pignus* of Roman law from which most of the modern law on the subject is derived. It differs from hypothecation and from the more usual kind of mortgage in being confined to personal property, and also in that the pledge is in the possession of the pledgee. A mortgage of personal property, in the majority of instances, takes the name and form of a bill of sale (*q.v.*). In the case of a pledge, it is held that a special property passes to the pledgee, sufficient to enable him to maintain an action against a wrongdoer, but the general property. *i.e.*, the property subject to the pledge, remains in the pledgor. As the pledge is for the benefit of both parties, the pledgee is bound to exercise only ordinary care over the pledge. He must, however, insure against loss by fire (35/36 Vict. ch. 93, s.36). The pledgee has the right of selling the pledge if the pledgor makes default in payment at the stipulated time.

The law of Scotland as to pledge generally agrees with that of England, as does also that of the United States. The main difference is that in Scotland and in Louisiana a pledge cannot be sold unless with judicial authority. Chattel mortgages, which differ from pledges in that the owner retains possession of the article, are uniformly required to be recorded in order to be valid against third parties, but except for a few States and aside from the Factors acts, a pledge, for the validity of which possession must be transferred to the pledgee, will be enforcible against third parties without being recorded. (*See* also Factors and Pawnbroking.)

PLEHVE, VIATSCHESLAF KONSTANTINOVICH (1846–1904), Russian statesman, was born of Lithuanian stock in 1846. He was educated at Warsaw and at the university of St. Petersburg (Leningrad) before he entered the department of justice, in which he rose rapidly to be assistant solicitor-general in Warsaw, then solicitor-general in St. Petersburg, and in 1881 director of the state police. As assistant to the minister of the interior he attracted the attention of Alexander III. by the skill he showed in investigating the circumstances of the assassination of Alexander II. He received the title of secretary of state in 1894, became a member of the council of the empire and in 1902 succeeded Sipiaguine as minister of the interior. Plehve carried out the "russification" of the alien provinces within the Russian Empire, and earned bitter hatred in Poland, in Lithuania and especially in Finland. He despoiled the Armenian Church, and oppressed the Armenians of the Caucasus. He certainly did nothing to discourage pogroms against the Jews, and he was credited with being accessory to the Kishinev massacres. His logical mind and determined support of the autocratic principle gained the tsar's entire confidence. He opposed commercial development on ordinary European lines on the ground that it involved the existence both of a dangerous proletariat and of a prosperous middle class equally inimical to autocracy. He was a determined and successful opponent of Witte's policy. An attempt was made on his life early in 1904, and he was assassinated on July 28 of the same year by a bomb thrown under his carriage as he was on his way to Peterhof to make his report to the tsar; the assassin, Sasonov, was a member of the socialist revolutionary party.

PLEIAD, in Greek literature, the name given (by analogy from Pleiades) by the Alexandrian critics to seven tragic poets who flourished during the reign of Ptolemy Philadelphus (285–247 B.C.). In French literature, in addition to the Pleiad of Charlemagne, there were two famous groups of the kind. The first, during the reign of Henri III. (1574–89), the chief member of which was Pierre de Ronsard, sought to improve the French language and literature by enthusiastic imitation of the classics; the second, under Louis XIII. (1610–43), consisted of authors who excelled in the composition of Latin verse.

PLEIADES, the constellation so called is in mythology the seven daughters of Atlas and Pleïone, and sisters of the Hyades. Owing to their grief at the death of their sisters or at the sufferings of their father, they were changed into stars. In another account, the Pleiades and their mother met the amorous hunter Orion (*q.v.*) in Boeotia; for five years he pursued them through the woods, until Zeus translated them all—Pleïone and her daughters, Orion and his dog—to the sky. This is one of the few myths really astronomical in origin, for it is based on the relative positions of the constellations in the sky. The names of the sisters are Alcyone, Asterope, Electra, Kelaine, Maia, Merope, and Taygete (Hesiod fr. 275 Rzach); one is always dim or invisible, because she is Electra mourning for Troy, or Merope, who is ashamed of having wedded a mortal, Sisyphus. All the Pleiades became the ancestresses of divine or heroic families. The spring rising and early winter setting of the Pleiades (Lat. *Vergiliae*) are important dates to the farmer.

See H. J. Rose, *Handbook of Greek Mythology* (1928).

The stars are situated in the constellation Taurus. They are supposed to be referred to in the Old Testament (Job ix 9, xxxviii. 31). The brightest star is Alcyone (3rd magnitude); Pleïone and Atlas are also of the 3rd magnitude. This group is physically connected, being distinguished from the background stars by community of proper motion. Photographs show a faint nebulosity filling the whole region; there is little doubt that this is rarefied matter made luminous by stimulation of the radiation of the hot stars comprised in it. The distance of the Pleiades is estimated at 100 parsecs (300 light-years), but is not very certainly known. Alcyone and the other bright stars are of the hottest type of spectrum (Type B), and give out several hundred times as much light as the sun.

PLEISTOCENE (Gr. *πλεῖστον*, most, and *καινός*, recent), in geology the epoch which succeeded the Pliocene. The Pliocene is now usually considered the last of the Tertiary period and hence the Pleistocene forms the lower subdivision of the Quaternary era. The period saw the arrival of the great Ice age (*see* Glacial

PERIOD) and the Pleistocene and Glacial period are sometimes used as if synonymous. The general geology of the period is considered under QUATERNARY.

PLEKHANOV, GEORGY VALENTINOVITCH (N. BELTMAN) (1857–1918), the founder and for many years the chief exponent of Russian philosophic Marxism, was born on Nov. 26, 1857, in the province of Tambov, of an old noble family. His father wished him to enter the army, but while a student he joined the Narodnist (populist) revolutionary movement. In 1876 he led the first great popular demonstration at St. Petersburg (Leningrad) in the Kazansky square. When the majority section of the Narodnists adopted terrorist methods in 1879, Plekhanov seceded, and with Deutsch, Axelrod, Vera Sassulitch and Ignatov, formed the Marxist "Liberation of Labour" group in Geneva (1883). He spent 40 years in exile, chiefly at Geneva, from which town he became the intellectual leader of the Russian Social-Democratic movement, in particular playing a large part in Lenin's early mental development. In the '90s and the early years of the 20th century the two men were closely associated. In Dec. 1900 was founded the S.D. journal *Iskra* (The Spark) of which Plekhanov was joint editor with Lenin, Martov, and others. In the first split of the Russian S.D. Party in 1903 Plekhanov was largely on the side of the Bolsheviks, holding views closely akin to those of Lenin.

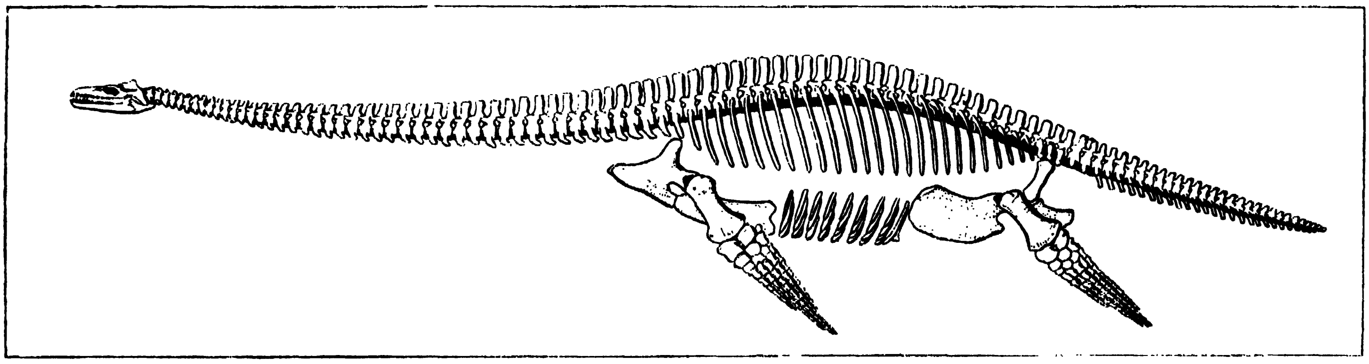
After the resignation of the Mensheviks from editorship of the *Iskra* Plekhanov and Lenin were joint editors, but some months later differences arose between them on the question of collaboration with the Mensheviks, and Lenin resigned. Thenceforth for several years Plekhanov worked with the Menshevik section of the party, but after 1907, while remaining a Menshevik, he took up an attitude on many issues, particularly on the question of participation in the State Duma and also on illegal activities, in agreement with that of the Bolsheviks. At the end of 1910 he again co-operated with the latter in contributing to the Bolshevik *Zviezda* (The Star) but the alliance did not last long, and when the war broke out in 1914 Plekhanov was foremost in advocacy of the principle of "revolutionary defence" of the country against the Bolshevik policy of working for the defeat of the Government. After the March revolution he returned to Russia and was invited to join the Provisional Government. He refused, but actively supported the Government against the Bolsheviks, and remained an opponent of the Bolshevik revolution until his death in Finland on May 30, 1918.

Plekhanov had an enormous influence on the development of the Socialist movement in Russia. The Moscow Marx-Engels Institute has published a complete edition of his works in 26 volumes. His biggest work is available in German: *Beiträge zur Geschichte des Materialismus*.

PLENER, ERNST, FREIHERR VON (1841–1923), Austrian politician, was born on Oct. 18, 1841, at Cheb in Bohemia, the son of the Austrian statesman Ignaz von Plener (1810–1908). From 1888 onwards he was the acknowledged head of the German Liberals in their struggles against the Slav-Conservative majority in the Chamber. Consequently he represented Germanism on the nationalities question, but was not averse to concessions compatible with the maintenance throughout the whole monarchy of the position due to the German Austrians. He sought to compromise the quarrel between Germans and Czechs, and the so-called "points" of 1890, a summary of the bases for a German-Czech understanding, were essentially his work. In the Windischgrätz Coalition Ministry (1893–5), Plener took over the portfolio of Finance. Soon after his retirement from the Finance Ministry, Plener was appointed president of the Supreme Audit Department (*Oberster Rechnungshof*). He entered the Upper House in 1900, and died on May 1, 1923.

Plener wrote a series of economic and political works, among others *Die englische Fabriksgesetzgebung* (1871); *Englische Baugenossenschaften* (1873). He published *Erinnerungen*, 3 vol. (1911–21).

PLESIOSAURUS, technically the name of a genus of extinct reptiles of the group Sauropterygia; it is commonly used to apply to all the later members of that group. The typical plesiosaurs are completely adapted for a marine existence in the open sea. They first appear in the Rhaetic and are last seen in the Upper Cretaceous. A typical plesiosaur has a small head with a large mouth and slender pointed teeth adapted to the catching of fish. The neck is long, often four times as long as the head. The body is relatively short, as is the tail. All four limbs are converted into paddles, no external trace of the fingers being visible.



FROM THE "CATALOGUE OF MARINE REPTILES OF THE OXFORD CLAY"

SKELETON OF MURAENOSAURUS, A LONG NECKED PLESIOSAUR, FROM THE OXFORD CLAY OF PETERBOROUGH, ENGLAND

From these forms two main evolutionary lines appeared. In one, the animals adopted the habit of living on large prey which they captured by their superior speed; in this line the head grew bigger and the neck shorter until it became no longer than the head. The body is comparatively long, the tail little more than the pointed hinder extremity of the body. The paddles become very large indeed, the hinder pair being bigger than the front ones. The largest members of this group are the plesiosaurs from the European Jurassic. In them the skull may be nearly 6 ft. in length and an individual tooth a foot long. In an animal whose head was just under 5 ft. in length the whole creature had a length of some 16 ft., and the hind paddles were about 5 ft. long.

The other line consists of animals which fed on small quick-moving prey which they seem to have captured by sudden lateral movements of the head and neck. Its most recent member, *Elasmosaurus*, is found in the Upper Cretaceous of Kansas, England, Queensland and New Zealand. In it the head is about 18 in. in length, the neck with as many as 76 vertebrae may reach a length of 19 ft., and the total length of the animal about 30 ft. The paddles of such an animal were about 3 ft. in length. Some plesiosaurs had the interesting habit of eating pebbles which were kept in the stomach to assist in grinding up food. Although the majority of plesiosaurs were marine, some few are always found in estuaries or freshwater deposits. *See* REPTILES.

(D. M. S. W.)

PLEURISY or **PLEURITIS.** A medical term for inflammation and the effects of inflammation affecting the pleura (*see* COELOM AND SEROUS MEMBRANES). Pleurisy may be induced mechanically, *e.g.*, by a blow, but more commonly is the result of microbial infection whether conveyed directly by the blood (as in scarlatina) or extending to the serous membranes from an inflammatory focus in the lung or adjacent part.

The condition may be acute or chronic. In acute pleurisy the normal glistening appearance of the serous membrane is lost, it becomes injected with blood, roughened from the deposition of fibrin from the serum that exudes from the dilated and inflamed blood vessels and so long as the two surfaces are in contact occasions much pain from friction during respiration. The amount of serum poured out into the pleural cavity and the amount of fibrin formed vary within wide limits. The fluid may accumulate to such an extent that there is bulging outwards of the intercostal spaces and the lung is rendered airless and compressed at the back of the pleural cavity close to the vertebral column. The fibrin may form a thick white felty layer over the entire lung.

The subsequent history of a pleurisy varies. If the effusion of fluid causes respiratory or cardiac distress surgical removal (thoracentesis) of a portion of the fluid is necessary; lymphatic and venous drainage are effective in removing the remainder. There may then be complete recovery, the compressed lung resuming its function if it has not been left compressed too long. In other cases fibrous adhesions, formed by the same process as that which leads to scar tissue (*see* PATHOLOGY) bind the two layers of the pleura together over a greater or less extent of their surface. The condition is then one of chronic pleurisy and recrudescences of inflammation with local pain and effusion of fluid may occur. If the pleurisy arise by extension from a pulmonary, diaphragmatic, costal or pericardial focus of disease its character is determined by that of the primary focus. If tuberculous, tuberculous nodules are found in the thickened material covering and replacing the normal serous membrane; if malignant disease the nodules are cancerous and the fluid often contains many red blood cells; while if the primary focus be that form of pneumonia which is caused by the pneumococcus and is characterized by the local output of numerous leucocytes, the pleurisy will be similar and frequently purulent (*see* EMPYEMA).

The symptoms and signs of pleurisy present difficulty. Where the patient complains of a sharp pain in the side especially on drawing a deep breath, the normal resonant note on percussion of the chest is replaced by a dead, dull note, the breath sounds are barely audible and the ear applied to the chest detects a rubbing sound, a diagnosis of pleurisy is easy. But the relative infrequency of these phenomena and the very great frequency with which pleural adhesions, often of wide extent, are found in the post-mortem room without the slightest indication that the patient during life complained of symptoms such as the appearances would seem to suggest, indicate that pleurisy is often symptomless. The inference is that pleurisy is very common, but comparatively rarely calls for medical or surgical treatment.

Treatment.—In many cases strapping of the affected side to limit movement is sufficient; where effusion becomes purulent and thoracentesis will be insufficient, a wide opening into the pleural cavity with removal of portions of one or more ribs to provide drainage becomes necessary. (W. S. L.-B.)

PLEURONECTIDAE, the family of fishes to which the name "flat-fish" is popularly applied. It includes the sole, flounder, turbot and plaice (*qq.v.*). (*See* FISH.)

PLEURO-PNEUMONIA or LUNG-PLAGUE, a contagious disease peculiar to the bovine species generally affecting the lungs and pleura, producing a particular form of lobar or lobular pleuro-pneumonia, and, in the majority of cases, transmitted by the living diseased animal, or, exceptionally, by mediate contagion. Cattle and closely allied species are susceptible; other animals and man are immune. Inoculation of healthy cattle with the fluid from the diseased lungs produces, after a certain interval, characteristic changes at the seat of inoculation, and though the inoculated animal does not develop the lung lesions always observed in natural infection, yet there is a local anatomical similarity or identity. In 1888 Arloing, of Lyons, described various bacilli obtained from the lesions of lung-plague. The cause is now held to be a polymorphic micro-organism capable of passing through ordinary bacterial filters. With a high magnification, coccal-like bodies, vibrios, short spirilla, branching and asteroid bodies, also mycelioid moulds may be seen. Fine mucin coverings are always present and for the latter reason the name Asterococcus mycoides was formulated by Borrel.

The earliest notices of this disease testify that it first prevailed in Central Europe, and in the 18th century it was present in certain parts of Southern Germany, Switzerland and France, and had also appeared in upper Italy. In 1769 it was definitely described as prevailing in Franche-Comté by the name of "muric." From that date down to 1789 it appears to have remained more or less limited to the Swiss mountains, the Jura, Dauphiné and Vosges, Piedmont and upper Silesia; it showed itself in Champagne and Bourbonnais about the time of the Revolution, when its spread was greatly accelerated by the wars that followed. In the 19th century its diffusion was accurately determined. It invaded Prussia in 1802, and soon spread over north Germany. It was first described as existing in Russia in 1824; it reached Belgium in 1827, Holland in 1833, the United Kingdom in 1841, Sweden in 1847, Denmark in 1848, Finland in 1850, South Africa in 1854, the United States—Brooklyn in 1843, New Jersey in 1847, Brooklyn again in 1850, and Boston in 1850; it was also carried to Melbourne in 1858, and to New South Wales in 1860; New Zealand and Tasmania in 1864; and also into Asia Minor. During the 20th century it has occurred in Asia, Africa, Australia, South America, Russia, Germany, France and Spain.

It has now been eradicated, or the incidence very much reduced, in most countries by compulsory slaughter and veterinary police measures. Great Britain has been free since 1898.

Symptoms and Treatment.—After a period of incubation of 12–16 days (after inhalation Nocard and Roux) or a little longer, loss of appetite and fever are apparent, accompanied by a dry, painful cough, which later becomes more frequent and moister. Pulse and respiration are accelerated with the customary signs of acute pulmonary disease. Generally the disease persists for some weeks before death supervenes, or apparent recovery ensues, with a later recrudescence of symptoms. High temperature with death in a few days is less common. Recovered cases should be regarded with suspicion.

Willems of Hasselt (Belgium) 1852 introduced protective inoculation, employing lymph obtained from a diseased lung; since that date the protective value has been proved in the field. Not entirely free of danger, the method appears to confer a temporary immunity. The inoculation is made in the extremity of the tail. In France, Nocard and Roux have used as a vaccine, an eight days' old culture of the virus in Martin's broth. Injected in the same manner, the method has given good results. An anti-serum, capable of conferring a passive immunity, has also been prepared. The disease is scheduled in Great Britain under the Diseases of Animals Act. (A. R. S.)

PLEVNA (Bulgarian *Pleven*), a city in Bulgaria; on the Tutchinitza, and Sofia-Varna railway (opened in 1899). Pop. (1906), 21,208. A branch line, 25 m. long, connects Plevna with Samovit on the Danube, where a port has been formed. After the events of 1877, it was almost entirely forsaken by the Turks, and most of the mosques have gone to ruin; but, peopled now mainly by Bulgarians, it has quite recovered its prosperity, and has a large commerce in cattle and wine (*see* RUSSO-TURKISH WARS).

Plevna, a small and unknown town without fortifications, became celebrated as the scene of Osman Pasha's exploits. He left Widin on July 13 with a column consisting of some 12,000 men and 54 guns. Hearing that he was too late to relieve Nikopol, he pushed on to Plevna, where there was a small garrison and on July 19 he took up a position on the bare hills to the north and east. He was none too soon. General Schilder-Schuldner, commanding the 5th division of the IX. corps, which had just captured Nikopol, had been ordered to occupy Plevna, and his guns were already in action. On July 20, having made no preliminary reconnaissance, the Russian commander advanced his infantry in four separate columns. On the north flank they pressed into Bukova, and also succeeded in driving back the Turkish right wing; but in both cases Turkish counter-attacks pressed back the Russians, with the result that by noon they were in full retreat, having lost 2,800 men out of a total of 8,000. The Turks lost 2,000. Osman at once drew up plans for the fortification of the position, and the